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Abstract

The world aquaculture industry seeks sustainable production strategies to respond to the needs of the growing world population for valuable food. Biofloc technology (BFT) is accepted as a novel sustainable method that reduces the pollution load on receiving water resources with its zero-water-discharge approach, eliminates extra water treatment costs with its biological cycles, and supports the growth performance of reared animals and thereby reduces feed costs. However, each BFT system has its own set of difficulties and obstacles. This review focuses on the advantages and disadvantages of BFT systems in terms of economy, sociability and applicability. The BFT shows more effective results in the conversion of toxic nitrogenous compounds to nontoxic compounds compared with the technologies based on nitrification processes. In addition, the growth performance and health of the cultured animals are generally better in BFT systems than those in conventional rearing systems (continuous water flow). The risk of common diseases occurrence due to pathogenic microorganisms appears to be lower in BFT systems compared to conventional aquaculture. It is also noteworthy that the immune system, biochemical stress indicators and antioxidant activities of organisms held in BFT systems are positively affected. In BFT systems based on microbial activity, the high water temperature demanded by bacteria is a limiter for the system. Moreover, a higher aeration/energy requirement is the case in BFT to meet the oxygen demand of all organisms including fish, shrimp, heterotrophic bacteria, nematodes, rotifers and others inside. There is also another concern about the acceptability potential of the cultured organism in BFT systems for consumption. Finally, since the high temperature demand of the system will create high energy costs, it should be considered as another restriction that forces the application. Considering the advantages and disadvantages of BFT systems as sustainable aquaculture, this review provides a guide for future studies and full-scale implementations.

Key words: biofloc, sustainable aquaculture, organic waste, fish

In 2020, global fisheries and aquaculture production has become a huge industry with an economic value of $424 billion (FAO, 2022). The global seafood production is higher than poultry and cattle-raising today. However, it will not response to meet the demand of the world population (probably 9 billion people) in 2050. Although a great bounce, the increase in production between 2016 and 2018 is considered insufficient, and global aquaculture production should double (Vasava et al., 2020). In other words, the aquaculture production target should be achieved to meet the food demand of the world, where 3 billion people today do not have access to healthy food at the required level.

Seafood production, an important food sector, is facilitated via fisheries and aquaculture. Interest in aquaculture is increasing (Khanjani and Sharifinia, 2020) because the amount of production via fisheries (considering natural stocks) is insufficient (Boyd et al., 2020; Dawood, 2021). Thus, fish must be raised at increasing levels but through sustainable methods (Frankic and Hershner, 2003). Otherwise, environmental and economic problems are likely to arise in the long run (Piedrahita, 2003; Sharifinia et al., 2018).

The decrease in access to clear water sources limits the sustainable increase of aquaculture production. Moreover, existing water quality problems due to climate change such as sudden temperature changes, algal blooms and decreases in water flow rates, also endanger the growth of the aquaculture sector. Given the decrease in access to water resources, many alternative methods of sustainable water use in aquaculture are being studied, including the reuse of treated water (Turcios and Papenbrock, 2014). The flow-through system, which involves single-water-use, is a production model that has been under debate in recent years from a point of sustainable water utilization considering that water quality changes are difficult to control in flow-through systems (Cullis et al., 2018). Recirculating aquaculture systems (RASs) use significantly less water than traditional flow-through farming systems (Martins et al., 2010). However, the RAS systems are not preferred by many farmers due to their high installation and operating costs as well as management issues (Badiola et al., 2012).

In addition to the water requirement in aquaculture, another important issue is to provide better feed conversion ratios and thus reduce the feed usage. Feed accounts for 60%–70% of total production costs (Gutierrez-Wing and Malone, 2006). Fishmeal and fish oil remain one of the major narrow pass against aquaculture growth since their production has been fairly limited for decades. About 18 million tons of 156 million tons in production from capture fisheries were destined to produce fish meal and fish oil in 2018 (FAO, 2020). Therefore, researchers have been studying alternative feed resources in recent years to reduce the dependence on fishmeal and oil and thus promote sustainable aquaculture production.

Sustainable aquaculture has three important goals. Firstly, producing more fish without increasing the use of basic natural resources, such as river and lake (Avnimelech, 2009). The two other goals are the development of sustainable aquaculture systems that will not damage the environment and the creation of systems that provide good cost/benefit ratios to support economic sustainability (Avnimelech, 2009; Naylor et al., 2000). In light of these goals, some improvements can be implemented socially, economically and environmentally in aquaculture via methods such as the use of alternative feed sources, use of RASs, treatment of discharge water and reduction of energy consumption (Boyd and McNevin, 2015). However, these approaches may still fail to fully meet the three goals. Biofloc technology (BFT) has potential to fulfil the majority of these requirements for aquaculture, given its low installation and operating costs, environmental friendliness, use in complex facilities and easy acceptance by farmers.

The concepts of biofloc technology

BFT is a new emerging production system that creates protein-rich recycled feed in the form of biofloc based on heterotrophic bacteria growth in a suitable C/N ratio, which essentially removes ammonia from water (Avnimelech, 1999; Crab et al., 2012). An organic carbon source is introduced to the rearing unit to provide the necessary C/N ratio for the growth of heterotrophic bacteria. The cost and sustainability of the carbon source are crucial issues in BFT (Wilén et al., 2000). Different carbon sources, such as starch, tapioca, wheat, corn, rice, molasses, sucrose, dextrose and glycerol, have been used in BFT (Azim and Little, 2008; Crab et al., 2010; Emerenciano et al., 2012; Gaona et al., 2011; Megahed, 2010). The carbon source is added to water through various strategies in BFT: direct addition of the carbon source to the growing medium, the addition of vegetable flours to feed and adjustment of dietary C/N ratio (Azim and Little, 2008; Taw, 2010). The biofloc composition can differ depending on the carbon source used and the method of use. Hollender et al. (2002) and Oehmen et al. (2004) recorded changes in water quality and obtained different protein and amino acid values from the biofloc content when they used various carbon sources (Deng et al., 2018; Ekasari et al., 2014; Wei et al., 2016). Goldman et al. (1987) reported 10:1 as the optimum C/N ratio for biofloc formation, but successful results have also been reported from other studies using ratios ranging between 10:1 and 20:1 (Panigrahi et al., 2018; Xu et al., 2016). The amounts of carbon source and feed for BFT should be calculated to maintain the desired C/N ratio. The C/N ratio is calculated by considering the amount of nitrogen and carbon entering the ambient from the feed needed by the organism in the culture medium.

BFT aims to facilitate aquaculture with zero or minimal water change by involving heterotrophic bacteria-driven aggregates including microalgae, zooplankton, algae, bacteria, protozoans and nematodes (De Schryver et al., 2008). The floc particles have sizes between 50–2000 µm (De Schryver et al., 2008) and consist of approximately 10–1.000 million microbial cells per cubic centimeter (Kumar et al., 2018). Over time, due to the nitrogen uptake by organisms of increasing numbers and species, the amount of ammonium in the water, a toxic substance generated by the reared organism in the system as a waste of protein metabolism, naturally begins to decrease (Schneider et al., 2005), thereby reducing the ammonium concentration more rapidly than nitrification (Hargreaves, 2006). Thanks to this improvement in water quality, more intensive aquaculture farming can be applied without increasing the amount of water used (Krummenauer et al., 2011, 2014). That said, an important issue is the requirement of 24-hour continuous and strong aeration. Although the aeration system varies according to the species and the production system, they need to provide a homogeneous distribution of oxygen in the water, mix the water column and oxygenate the bottom sediment (Avnimelech, 2009). Generally, paddlewheel aerators, propeller aerators, vertical pump aerators and diffused air systems are used, but conventional aerators are preferred for ponds as they are inexpensive and easy to use (Lara et al., 2017 a).

With regard to BFT, the aims lie in improving water quality and producing protein-rich recycled feeds from dissolved and particle wastes of fish or shellfish being cultured (Avnimelech, 2009). In recent years, many studies have been carried out on alternative feed ingredients and additives that increase growth and strengthen the fish immune system (Dawood et al., 2018; de Sousa et al., 2019; Roques et al., 2020). The main target ingredient to reduce in fish diets is fish meal because the amount of it used is higher than the amount produced (Naylor et al., 2000). Terrestrial plant-based or animal based-feedstuffs as well as live feeds and trash fish are used by some businesses as alternatives to reduce feed costs (Lim et al., 2003), but none of these options appears to have the capability to completely replace pellet feed. Therefore, BFT appears to be an attractive and effective option, as the reuse of wastes and unconsumed feed with flocs will support the reduction of the feed conversion ratio (FCR). As a result of high crude protein in biofloc, which ranges between 38–50% on dry-matter basis (Azim and Little, 2008; Webster and Lim, 2002), many studies on fish and shrimp (Avnimelech et al., 1994; Burford et al., 2004) have observed significant improvements in growth and feed utilization performance. Biofloc contains higher levels of protein than many pellet feeds, meaning that it can be used as a bonus food source, helping reduce dietary protein levels of the feed formulated for the cultured species.

The advantages of BFT

Water quality

Today, the importance of protecting the environment and eliminating potential wastes at their sources is acknowledged by all food production methods. For example, new and environmentally friendly systems are encouraged in the aquaculture sector. Since the acceptance of BFT as a sustainable production method in aquaculture, studies have generally focused on rearing water quality. In intensive aquaculture with zero water discharge, a high nutrient input encourages dense microorganism communities (Minaz and Kubilay, 2021). While some of the nitrogen, carbon, and phosphorus from the feeds are used by organisms cultured, the majority of them are released into the aquatic environment (Avnimelech and Ritvo, 2003; Cao et al., 2007). Heterotrophic bacteria in the water incorporate organic pollutants into their biomass at the appropriate C/N ratios (Khanjani and Sharifinia, 2020; Schneider et al., 2005). The quality of water maintains at an appropriate level without water renewal, as the bacterial communities that develop with the dissolved organics are consumed by fish and crustacea (Kuhn et al., 2010; Xu et al., 2016).

Any deterioration in the water quality negatively affects the stress indicators in fish physiology such as serum Na+, Ca+2, and cortisol (Kurtoğlu et al., 2021). In this regard and especially for fish welfare, nitrite, nitrate, and ammonium concentrations in the rearing water should be routinely monitored (Timmonsand and Ebeling, 2010). In RASs, ammonium is particularly subjected to the nitrification process in the biological filtration unit because it is very toxic for the cultivated species (Badiola et al., 2012). However, BFT systems do not have biological filtration. Instead, in these systems, ammonium is directly consumed by heterotrophic bacteria at much faster rate (Hargreaves, 2006). According to the Illumina sequencing analysis of ammonia-oxidizing bacteria in the V3 region in a study by Deng et al.

(2018), the diversity of bacterial community in biofloc systems is much wider than in clear water systems, which accelerates the reduction of ammonia concentrations.

In many studies on BFT systems, it has been emphasized that water quality was improved in terms of ammonia nitrogen and nitrite nitrogen levels (Dauda et al., 2018; Kaya et al., 2019 b; Khatoon et al., 2016; Kumar et al., 2018; Luo et al., 2019; Menaga et al., 2019; Panigrahi et al., 2018, 2019; Panigrahi et al., 2020 a; G. Wang et al., 2015). However, in a limited number of studies, water quality parameters in BFT systems were not affected at all compared to control groups based on flow-through systems (Chen et al., 2020; Fleckenstein et al., 2018; Pérez-Fuentes et al., 2016). According to a study by Mansour & Esteban (2017), although water quality parameters including ammonia and nitrite in BFT system did not exceed toxic values for Nile tilapia, they were adversely affected compared to the control group. Similarly, in a study with carp, TAN, nitrite and nitrate levels of water managed with BFT groups were observed to be higher than in the control group (Bakhshi et al., 2018). Higher values for TAN observed in the BFT groups in the first 30-day period compared with the clear water control treatment decreased significantly in the following period (Aalimahmoudi and Mohammadiazarm, 2019). In another study, it was observed that ammonium and nitrite nitrogen peaked between the first 30–45 days, and decreased below 2 mg L^{-1} and 0.5 mg L^{-1}, respectively, in the following period (Zhang et al., 2016). In another study conducted with common carp at different stock densities, TAN concentrations increased in the control groups after the 18th day, a trend which was opposite to the concentrations in the BFT (Adineh et al., 2019).

In BFT systems with different configurations, as a result of the presence of flocs and aquatic animals in the same tank, the number of bacteria will increase rapidly in parallel with the concentration of suspended solids (Liu et al., 2019). High aeration in BFT ponds or tanks is important due to needing for ammonia assimilation by heterotrophic bacteria, oxygen consumption by respiration of blooming growth of bacteria, and consumption of cultured organisms, moreover the carbon source added to the tank will result in a decrease in the dissolved oxygen concentration (El-Hawarry et al., 2021; Gaona et al., 2016).

Another parameter that is monitored in BFT systems to control the water quality is the total suspended solids (TSS) concentration (Schveitzer et al., 2013). Time-dependent biofloc volumes increased in connection with the shrimp biomass (Harun et al., 2019). It is noteworthy that high TSS concentrations had a positive effect on BFT cultivation. Although it is not always the case in BFT systems, Gaona et al. (2016) observed that increasing TSS concentrations significantly increased nitrite nitrogen while decreasing ammonia and nitrate nitrogen. Heterotrophic bacteria have a much higher growth rate and ability to reduce ammonium concentration per unit substrate than nitrifying bacteria (Hargreaves, 2006). In another study, while there was no significant difference between increasing TSS concentrations and water quality values, the weight gain of gibel carp increased significantly when the TSS was 800 and 1000 mg L^{-1} (Qiao et al., 2018). In contrast to these studies, in another study, weight gain and survival rate were significantly reduced when the TSS was 745 mg L^{-1} (Gaona et al., 2017).

The findings summarized suggest that relationships among the water quality parameters are not always the same in BFT systems due to highly dynamic factors.

Growth performance

The main purpose of aquaculture is to develop and implement strategies allowing a high growth performance. The increase in stocking density will increase the dependence on fish feeds (Liu et al., 2019). This situation will lead to a soar in cost for the producer and nutrient loads to the environment. In this context, the BFT system appears to be a great alternative production method as it keeps the wastes in the culture unit and transforms them into biofloc as supplemental food for cultured species or shellfish (Azim and Little, 2008). The presence of heterotrophic bacteria, which is the most important working mechanism of BFT, improves the weight gain and feed conversion rates of aquatic organisms (Bossier and Ekasari, 2017). Studies on carp culture have reported that their growth performance is positively affected by the application of BFT systems compared to control group (clear water system) (Liu et al., 2019; Qiao et al., 2018). BFT in genetically enhanced tilapia was investigated using diets (containing biofloc meals). Growth performance and productivity were higher in BFT groups than in the control group (Menaga et al., 2019). Similarly, in fish fed with feeds with different protein ratios, the net yield was higher in BFT tanks regardless of the protein ratio in the feed (Azim and Little, 2008).

Growth rate, FCR, and total productivity parameters in aquaculture are interrelated. Optimum levels of these parameters under suitable conditions can be achieved with the right feeding protocols. In BFT systems, feeding regimes can be improved by allowing the use of flocs as additional feed (Minaz and Kubilay, 2021). In a study, feeding frequency and feeding regimens were examined together in both BFT and control groups (Kaya et al., 2019 b). For each of the four scenarios tested, shrimp growth performance in BFT tanks was found to be significantly higher than in control groups (clear water system). A study aiming to examine biofloc as an additional nutrient source by gradually reducing the feeding rates found significantly higher growth performance in *C. carpio* was observed in the 100% fed control group and 75% fed BFT group (Najdegerami et al., 2016). This study clearly demonstrated the potential of biofloc as an additional nutrient source. The effects of feeds with gradually decreasing macroalgae and gradually increasing biofloc content in sea cucumber (*Apostichopus japonicus*) cultivation were investigated (Chen et al., 2018). The inclusions of biofloc at 20% or 30% in diets had a positive effect on the growth performance of the sea cucumber. Another study that examined BFT technology under a restricted feeding regimen reported that the SGR value was not adversely affected by reducing the feeding rate up to 85% (Aliabad et al., 2022). In addition, the BFT group showed a higher growth performance than the control group for all conditions.

Probiotic and symbiotic applications in aquaculture studies positively affect the growth performance and health conditions of aquatic organisms (Kathia et al., 2017; Sutthi et al., 2018; Yazıcı et al., 2015). In a study by Laice et al. (2021), two different BFT groups were compared in the BFT-based Nile tilapia culture: a probiotic BFT group and a symbiotic (commercial symbiotic additive) BFT group. In particular, the weight gains and SGRs were higher in the symbiotic group. Because, symbiotics are a combination of prebiotics and probiotics that positively affect the animal by stimulating health-promoting bacteria and thus improving production performance and animal welfare. In another study, the use of probiotics in water and feed in the BFT system significantly increased the growth performance and survival rates of *L. vannamei* (Krummenauer et al., 2014). Putra et al. (2017) demonstrated that probiotic application at a 5-day interval was effective for the growth performance in a BFT-based African catfish culture. In contrast, some other studies that used probiotics showed no significant differences in growth performance in traditional BFT systems (Ferreira et al., 2015; Huerta-Rábago et al., 2019), suggesting that this topic remains to be further studied in more detailed methods.

Disease resistance

The aquaculture environment for the cultured animals should be within the limits of health, immunity and resistance to pathogens. Especially in developing countries, there is an economic loss of approximately 50% in aquaculture due to fish diseases (Assefa and Abunna, 2018). This loss negatively affects the producer directly and the consumer indirectly from an economic point of view. For sustainable production, it is necessary to focus on "prevention" instead of "treatment" of the diseases (Romero et al., 2012). For this purpose, BFT systems emerge as an innovative strategy, especially for disease resistance as can be deduced from the literature results summarized below.

Hostins et al. (2019) performed a challenge test against *Vibrio parahaemolyticus* with and without probiotic application using bacteria with different trophic levels in a BFT-based culture system. The challenge test was carried out in 3 different scenarios for *Litopenaeus vannamei* post-larvae; (1) replaced from BFT tank to BFT tank, (2) replaced from BFT tank to seawater tank, and (3) replaced randomly RAS to BFT tank. Transferred *L. vannamei* post-larvae from the BFT tank to the seawater tank, the survival rates were observed to be quite low compared to the other two scenarios, showing the effectiveness of BFT on disease resistance. BFT may have an effect on the quorum sensing regulation of *Vibrio*, reducing its activity and virulence towards the host (Crab et al., 2010). On the other hand, the BFT formed by autotrophic bacteria without probiotics resulted in low survival rates. Another study investigated the survival rates of *L. vannamei* maintained in BFT and clear water systems against *Vibrio harveyi* (Aguilera-Rivera et al., 2019). As a result of 10-day exposure, the survival rate of shrimp in the clear water group was observed to be lower than those in BFT. In another study, it was reported that the best survival rate for *O. niloticus* exposed to *V. harveyi* for 14 days was seen in fish raised by the BFT with stock densities of 166 and 333 individual/m^3 (Liu et al., 2018). In a study on gibel carp, the BFT rearing system showed a higher survival rate when challenged with *Cyprinid herpesvirus* 2 compared to the control group (Qiao et al., 2018). In a study, it was observed that the survival rate of Nile tilapia larvae obtained from the broodstock fish grown in the BFT system was quite high compared with the larvae from broodstocks grown in the control group (clear water system) when exposed to *Streptococcus agalactiae* (Ekasari et al., 2015). African catfish reared in the BFT systems with C/N ratio of 15 or 20 had significantly higher survival rates against *Aeromonas hydrophila* than those in the control group (Dauda et al., 2018).

Fish diseases are the most critical narrow pass in the aquaculture industry. Therefore, every development in the fish diseases will make more comfortable to aquaculture facilities. Because the losses caused by fish diseases in aquaculture are considered to be at the highest level. We supported that BFT can play a major role for decreasing of mortality against pathogen microorganisms.

Enzyme activities, immune response, stress and antioxidant parameters

Compared to clear water aquaculture systems, BFT systems are advantageous not only in terms of water quality or growth performance but also in the improvement of the immune system, antioxidant, and stress parameters of raised organisms. The flocs in these systems contain high amounts of bioactive compounds in different compositions. For instance, one group of these compounds, carotenoids, improves aquatic animals' immunity and increases their stress tolerance and antioxidant function (Babin et al., 2015). A study performed on Nile tilapia maintained in the BFT system examined the digestive enzyme activities, immune response, stress, and antioxidant parameters at different stock densities of fish (Liu et al., 2018). The results showed that stocking densities of 166 and 333 individuals/m^3 had a significantly positive effect on all parameters compared with the control group. In another study that examined digestive activity, antioxidant, and stress parameters in genetically improved tilapia, no significant differences in alkaline phosphate, lysozyme, and glucose levels were observed between fish in the BFT and control groups, while the total superoxide dismutase level was higher in the BFT tank (Luo et al., 2014). In addition, protease activity did not differ significantly between the BFT and control groups, while lipase activity in the BFT was lower in the intestine and higher in the stomach. In a study, the specific amylase protease, lipase, and cellulase activities in the hepatopancreas, stomach, and intestines of shrimps (*L. vannamei*) grown in the BFT tank were similar to or significantly higher than those in the control (Wang et al., 2016). Another study on common carp (*C. carpio*) reported that the amylase and protease activities of fish grown in the BFT system were higher than in the control group (Adineh et al., 2019). High levels of catalase, SOD, malondialdehyde, and glutathione peroxidase were noted particularly in fish reared at the high-densities than those in the control group. Further, the prophenoloxidase activity and SOD value for two different shrimp species (*Penaeus vannamei* and *Penaeus indicus*) were higher in the BFT group than in the control group (Panigrahi et al., 2020 b).

As a result of this section, BFT system has physiologically, histologically, immunologically, and economically numerous and different type of positive effect on fish. Fish farming facilities should be raised an awareness in terms of sustainable aquaculture techniques such as BFT. The most important way of this approach is directly related to increased economic value of facility. As an scientist and researcher in fisheries and aquaculture, we need to consider this issue in the agenda.

The disadvantages of biofloc technology and its minimization approach

Cultured species

The BFT, due to its working principles, focuses on the welfare of the heterotrophic bacterial community in the environment to keep the water quality within the optimum ranges for fish or shellfish being cultivated. Therefore, BFT strongly influences harvest yield by providing suitable water quality over the culture period (Crab et al., 2012). The water temperature required for the bacterial community within BFT limits the species available for the system. The BFT systems work more efficiently at higher water temperatures and are mostly studied in tropical regions. Therefore, cold-water fish species or fish farms functioning in northern countries may have difficulty with the application of BFT systems. In other words, to keep up with the development of aquaculture trends, it is necessary to focus on alternative species in terms of suitability for the BFT. In this context, BFT systems can make it possible to support sustainable farming in many countries and for others to turn to alternative farming types. BFT application in species grown in cold waters might raise awareness for cultivating alternative species. Considering the adverse effects of climate change on aquaculture globally, BFT systems, combined with greenhouse pools, can be innovative and applicable technologies for northerly countries for warm water fish and shellfish species (Crab et al., 2012).

To provide the living environment of heterotrophic bacteria in the BFT system, the appropriate C/N ratio is provided by adding carbon to the culture water. This causes an abrupt drop in the dissolved oxygen concentration in the water (Gaona et al., 2016). Sudden fluctuations in water quality and concentrations of the suspended solids in the BFT systems can stress cultured organisms. As a result, BFT culture is not suitable for oligotrophic species such as salmonids. However, various crustacea and fish species can potentially be cultivated in BFT systems. It is known that some parts of dietary fat, minerals and vitamins required for shrimp farming can be met with biofloc formed in the BFT. Several studies examine the effect of BFT on different shrimp species such as *L. vannamei* (da Silveira et al., 2020; Emerenciano et al., 2013; Furtado et al., 2015; Gaona et al., 2017; Xu and Pan, 2013), *Penaeus vannamei* (Kumar et al., 2018; Ponce-Palafox et al., 2019), *P. indicus* (Das et al., 2022; Panigrahi et al., 2021), *Metapenaeus monoceros* (Kaya et al., 2019 a, b), *Farfantepenaeus paulensis* (Emerenciano et al., 2011; Fóes et al., 2011), *P. monodon* (AftabUddin et al., 2020; Anand et al., 2014, 2017), *F. brasiliensis* (De Souza et al., 2014 a; Hostins et al., 2015) and *Marsupenaeus japonicus* (Kim et al., 2015, 2021; Zhao et al., 2012). In addition to shrimp farming in BFT systems, studies have been conducted on fish such as Nile tilapia (Azim et al., 2008; Ekasari et al., 2015; El-Hawarry et al., 2021; Pérez-Fuentes et al., 2016; De Souza et al., 2019; Van Doan et al., 2022), common carp (Azimi et al., 2022; Ebrahimi et al., 2020; Manzoor et al., 2020; Tabarrok et al., 2020), African catfish (Dauda et al., 2018; Diatin et al., 2021; Romano et al., 2018), *Mugil cephalus* (Hoang et al., 2020; Vinatea et al., 2018), *Labeo rohita* (Ahmad et al., 2019; Debdauda et al., 2020; Kamilya et al., 2017; Mahanand et al., 2013; Vadhel et al., 2020) and *Carrassius auratus* (Besen et al., 2021; da Cunha et al., 2020; Yu et al., 2020). Therefore, it is possible to produce the first two most cultivated species globally (Nila tilapia and common carp) with a sustainable aquaculture production method, the BFT. Culturing these species at high volumes with BFT systems will create ecological and economic added values. In addition, in societies where species that cannot be cultivated with BFT systems are produced intensively, BFT systems will allow the production of alternative new species and their consumption by humans. For instance, there is a study in which BFT experiments are carried out on *Piaractus mesopotamicus* (Sgnaulin et al., 2021). However, before scaling up the BFT production method in those species, more studies are required to better understand the dynamics of the BFT systems in larger systems and to be better prepared for the management issues and risks that can be met during the culture periods.

Energy cost

Floc formation in BFT systems is observed as a result of continuous aeration of the culture medium and agitation of the water column (Hargreaves, 2013). Continuous and strong aeration has different effects on the BFT system such as (1) providing oxygen to the organism cultured, (2) avoiding adverse effects of high stock densities, (3) ensuring the homogeneous distribution of oxygen in the BFT tank on the horizontal and vertical axis, (4) agitating the water column, (5) providing aerobic conditions by oxygenating the sediment, and (6) providing uninterrupted oxygen for the microbial community that provides nitrification (Avnimelech, 2009). However, continuous and strong aeration brings high operating costs. Different aeration equipment such as propellers, aero tubes, diffusers, airstones, paddlewheels, nozzles and vertical pump aerators can be used to keep the energy cost to a minimum (Lara et al., 2017 a). The turbulence generated by the aeration units affects the collection and breaking of flocs (Crab et al., 2012).

In a study conducted for the minimization of aeration in the BFT system, the effects of both continuous and intermittent (0.5-h aerated/0.5-h non-aerated) aeration were investigated (Liang et al., 2014). There were no significant differences between the groups in terms of nitrogenous compounds and biofloc content (crude protein and polysaccharides). Considering the energy cost, it was noted that intermittent aeration has a viable potential. In an integrated biofilm and biofloc study, the presence of nitrogenous compounds in an uncultured medium with different aeration rates was investigated by de Morais et al. (2020). There were no significant differences between the ammonia concentrations, while the nitrate concentrations were higher in the non-aerated group. Subsequently, a second trial was carried out on the group with 33.75 L/min aeration. Survival rates were better and toxic nitrogenous concentrations were lower for the *L. vannamei* culture in the biofilm group than in the BFT group. In a study examining the potential for BFT formation depending on the aeration unit, air stones and aero tubes were compared (Harun et al., 2019). Aero tubes resulted in higher water quality, biofloc volume and shrimp biomass due to more homogeneous mixing and circular water current. In a similar study, a propeller-aspirator pump aerator, vertical pump aerator and diffused air blower were used as aerators (Lara et al., 2017 a). The nitrification process was performed best in the diffused air blower group. In addition, the highest productivity was observed in the blower group. In another study, the effects of micro-bubble and macro-bubble aeration for BFT systems were investigated (Lim et al., 2021). The results showed that microbubble aeration improves water quality and increases the growth efficiency (FCR and SGR) of shrimps. Creating optimum conditions for the aeration process, which generally has high energy costs, can reduce operating costs and increase product yield. For this, it is essential to operate the aeration standby and to use different aeration units. In particular, the use of micro-aerator and blowers can be more efficient aeration units in BFT technology.

Consumer concerns

One of the most significant disadvantages of BFT systems is that the organism targeted to be consumed is directly involved in the nitrogen and carbon cycle (Minaz and Kubilay, 2021). The idea that the organisms in the culture medium are fed with nitrogen and carbon-based wastes may negatively affect consumer acceptance. In this context, sensory analysis and fillet quality of fish or shellfish held in BFT systems can increase costumer appeal and decrease possible consumer hesitation. In one study, moisture, protein, lipids and ash ratios of tilapia fillet and biofloc particles were examined using BFT systems with different carbon sources (Lima et al., 2018). The results showed no significant difference between the fillet quality of fish in the BFT and control group in terms of proximate composition, whereas biofloc itself had high protein and ash content. In the study, the results of the sensory analysis showed that the general appearance was better in the BFT, particularly in the sugar group as a carbon source. It has been observed that tilapia fish growth in the BFT system based on sugar was better and has a higher consumption appeal. A similar study was conducted for shrimp farming and no significant difference was observed between the BFT and control groups in the proximate analysis (Hussain et al., 2015). In a study on the use of biofloc as a feed for red tilapia, it was observed that the fillet moisture content was 72.28%, crude protein was 16.56%, crude lipid was 7.8%, and ash ratio was 2.78% (Delgado et al., 2020). According to the results of the proximate analysis and sensory tests performed on pirapitinga (*Piaractus brachypomus*) fillets fed with different protein sources under BFT conditions, no significant differences were observed between the treatments (Diaz et al., 2021). Sensory analysis results of shrimps grown under heterotrophic and photoautotrophic biofloc conditions were similar compared to the control group (Martinez-Porchas et al., 2020). Additionally, the cholesterol value of the shrimps belonging to the control group was observed to be significantly higher than the two BFT groups.

The presence of mineral salts in BFT systems causes an increase in osmotic pressure on the fish, which results in additional or diminished water absorption by the fish. The altered water absorption may affect the fillet quality. In a study conducted for this purpose, the sensory analysis results between the marine salt, common salt and no-salt groups revealed no differences between the groups (Silva and Piana, 2020). In addition, no differences were seen between the groups in terms of moisture, crude protein or minerals. In another study conducted with different salt ratios, red tilapia proximate analysis was examined at no-salt, 5 ppt, 10 ppt, 15 ppt and 20 ppt salinities (Kumari et al., 2021). The results showed lower moisture and higher dry matter, protein, ash and ether extract in 15 ppt and 20 ppt groups compared to other groups. In addition, the increase in salinity increased the color scale values. No significant differences were observed between the groups in the cooked or raw sensory analysis results. As a result, the increase in the salinity of the culture water for red tilapia is a factor that increases consumer appeal. Another study revealed that 5 ppt and 30 ppt salinity did not reflect a significant difference in sensory analysis in shrimp farming (Pinho and Emerenciano, 2021). Briefly, food quality variables should be included in future BFT studies to address the possible consumer concerns.

Sensitivity of water temperature

Environmental parameters such as temperature, pH and DO are vital for bacterial growth in the BFT systems (Avnimelech, 1999). Especially the temperature affects the growth performance, biomass composition, nitrate requirement and metabolic reaction of bacteria in the BFT system (Esener et al., 1981). Bacteria do not have the ability to keep their own temperature in balance, so biofloc tends to decompose at low temperatures, but increases in size at high temperatures (30–35°C) (Wilén et al., 2000). In a study conducted on goldfish, different temperature values were compared and it was reported that the survival rate and growth rate were significantly lower at 10 and 15°C. In addition, ammonium nitrogen was observed to be higher at low temperatures (Cho et al., 2015). The highest survival rate, growth performance and water quality were observed at 25 and 30°C temperatures. In another study, antioxidant activity was examined at 15, 21, 27 and 33°C and it was observed that 27°C temperature showed higher catalase and glutathione-S-transferase in shrimp (De Souza et al., 2014 b). The growth performance of pink shrimp at different temperatures was investigated by Hostins et al. (2015). The shrimps were placed to 30°C after the nursery stage (21°C and 30 days). The SGR of shrimp in this system were quite high compared to control group. Further studies are clearly required to fully explore the importance of water temperature for the development of cultured organisms and microbial communities in the BFT systems.

Requirement of qualified staff

The fisheries and aquaculture industries are needed to provide a portion of the animal protein necessary for the increasing world population (Ahmed et al., 2019). However, the interest in aquaculture is increasing, especially considering the risk of reduction in fish stocks (Minaz et al., 2021). Future projections predict that capture production will remain stable at around 93 million tons in the period of 2010–2030 (World Bank, 2013), while aquaculture production will reach 140 million tons in 2050 (Waite et al., 2014). This situation creates the idea that new employees will join the aquaculture sector. According to 2005 data, the number of personnel engaging in the aquaculture sector is 23.4 million directly and indirectly (Valderrama et al., 2010). According to the 2018 target, this number is aimed to reach 59.5 million people (FAO, 2020). Since the number of qualified personnel is a small part of this density, there will always be a higher need for qualified personnel in new aquaculture systems. In this context, qualified personnel should be trained to improve the BFT systems, especially against sudden failures. Because the environments where bacteria and culture organisms stay together must be kept under control. There are some examples of training qualified staff in different countries for various disciplines. For instance, the Canadian Integrated Multi-Trophic Aquaculture Network has provided highly qualified personnel for their interdisciplinary research (Chopin et al., 2013). A marine aquaculture project was supported for the training of qualified personnel in a center in Morocco (Touiri et al., 2020). As a result, education is indispensable for increasing the qualifications of personnel in aquaculture. In this context, e-Learning education can be an important alternative, especially in a way that does not intervene with the routine work of the personnel (Seixas et al., 2015).

Conclusions

The natural fish and shellfish stocks will not meet the increasing protein demand in the world even if the stocks are strictly protected. Therefore, the pressure on aquaculture will continue to increase day by day to meet the protein demand. This pressure will make sustainable production methods even more important to increase production capacities in more limited water, space, resource and climatic conditions. Sustainable developments in aquaculture should focus on achieving a high amount but healthy fish yields at a low cost. In this context, BFT appears to be an alternative solution to support sustainable aquaculture production worldwide. The current review study focuses on the advantages and disadvantages of technology by considering the economic situation, social pressures and applicability principles of the BFT system. According to this;

– Nitrogenous compounds have necessarily been monitored in studies for BFT and observed that these systems increase water quality if properly managed. By converting ammonium to microbial biomass and nitrate faster than nitrification processes, BFT systems create high water quality even at zero water discharge conditions.

– It has been noted that the animals reared in the BFT system generally show higher growth performance than traditional methods, suggesting that it meets the basic aims of the producer for sustainable aquaculture.

– Traditional aquaculture carries the risk of contamination by pathogenic microorganisms due to the high inflow and outflow of water from outside. Although this risk is at the minimum level in BFT systems, in many studies, higher survival rates of organisms grown in BFT systems against pathogenic microorganisms have been reported.

– In aquaculture, the immune system and physiological condition of animals must be strong for healthy and rapid growth. For this purpose, immune response, antioxidant activity, stress parameters and enzyme activities of species grown have been investigated in many studies in BFT systems. In general, the results showed that the animals grown in BFT systems did show significantly better or comparable results than the control group, suggesting at least that the BFT has no adverse effect on fish or shellfish.

– The variety of species that can be grown in BFT systems is limited. However, looking at the development projections of FAO and countries, in general encouragement of farming omnivore/herbivorous species is given importance instead of carnivorous species. The species most commonly grown in BFT systems are generally those fed at low trophic levels. In fact, this issue, which seems like a disadvantage at first glance, has great relevance in meeting the protein demand perspective.

– The BFT requires high and continuous aeration for micro and macro organisms in the system. Since this increases the operating cost, few optimization studies are available in the literature. In this context, further studies on the optimization of aeration need to be done to lower the cost of aeration.

– There is a concern about the consumption of animals grown in BFT systems. The available findings regarding the sensory analyzes and nutritional studies have shown that there is no difference between BFT and control groups. This means that fish and shellfish grown in BFT systems have high sensory and taste scores. Yet, future studies should include food quality traits of fish and shellfish by taking socio-economic measurements into account to encourage the consumption of aquatic food from the BFT systems.

– Another issue is the water temperature in terms of the favorable functioning of heterotrophic bacteria at higher temperatures in the BFT systems. Former studies have concluded that the water temperature between 25°C and 30°C seems to be optimal for the BFT systems. However, future studies should be carried out to investigate microbial abundance, diversity and function in varying temperatures.

– BFT systems can only be run by qualified staff. In case of a possible sudden failure, the BFT system must be recovered. Therefore, we suggest that specific aquaculture training programs for BFT systems should be arranged for future aquaculture engineers at universities or in public/private sector-supported education organizations.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Mert Minaz: Conceptualization, Methodology, Writing – Original Draft; İrfan Selçuk Yazıcı: Conceptualization, Investigation, Writing – Original Draft; Hüseyin Sevgili: Conceptualization, Supervision, Writing – Review & Editing; İlhan Aydın: Supervision, Writing – Review & Editing.

Data availability

All datasets used during the current study are available from the corresponding author on reasonable request.

References

Aalimahmoudi M., Mohammadiazarm H. (2019). Dietary protein level and carbon/nitrogen ratio manipulation in bioflocs rearing of *Cyprinus carpio* juvenile: Evaluation of growth performance, some blood biochemical and water parameters. Aquaculture, 513: 734408.

Adineh H., Naderi M., Khademi Hamidi M., Harsij M. (2019). Biofloc technology improves growth, innate immune responses, oxidative status, and resistance to acute stress in common carp (*Cyprinus carpio*) under high stocking density. Fish Shellfish Immunol., 95: 440–448.

AftabUddin S., Siddique M.A.M., Sein A., Dey P.K., Rashed-Un-Nabi M., Haque M.A. (2020). First use of biofloc technology for *Penaeus monodon* culture in Bangladesh: Effects of stocking density on growth performance of shrimp, water quality and bacterial growth.

Aquac. Reports, 18: 100518.

Aguilera-Rivera D., Escalante-Herrera K., Gaxiola G., Prieto-Davó A., Rodríguez-Fuentes G., Guerra-Castro E., Hernández-López J., Chávez-Sánchez M.C., Rodríguez-Canul R. (2019). Immune response of the Pacific white shrimp, *Litopenaeus vannamei*, previously reared in biofloc and after an infection assay with Vibrio harveyi. J. World Aquac. Soc., 50: 119–136.

Ahmad I., Leya T., Saharan N., Asanaru Majeedkutty B.R., Rathore G., Gora A.H., Bhat I.A., Verma A.K. (2019). Carbon sources affect water quality and haemato-biochemical responses of *Labeo rohita* in zero-water exchange biofloc system. Aquac. Res., 50: 2879–2887.

Ahmed N., Thompson S., Glaser M. (2019). Global Aquaculture Productivity, Environmental Sustainability, and Climate Change Adaptability. Environ. Manage., 63: 159–172.

Aliabad H. S., Naji A., Mortezaei S. R. S., Sourinejad I., Akbarzadeh A. (2022). Effects of restricted feeding levels and stocking densities on water quality, growth performance, body composition and mucosal innate immunity of Nile tilapia (*Oreochromis niloticus*) fry in a biofloc system. Aquaculture, 546: 737320.

Anand P.S.S., Kohli M.P.S., Kumar S., Sundaray J.K., Roy S.D., Venkateshwarlu G., Sinha A., Pailan G.H. (2014). Effect of dietary supplementation of biofloc on growth performance and digestive enzyme activities in Penaeus monodon. Aquaculture, 418–419: 108–115.

Anand P.S.S., Kumar S., Kohli M.P.S., Sundaray J.K., Sinha A., Pailan G.H., Dam Roy S. (2017). Dietary biofloc supplementation in black tiger shrimp, *Penaeus monodon*: effects on immunity, antioxidant and metabolic enzyme activities. Aquac. Res., 48: 4512–4523.

Assefa A., Abunna F. (2018). Maintenance of fish health in aquaculture: Review of epidemiological approaches for prevention and control of ınfectious disease of fish. Vet. Med. Int., 2018.

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

Avnimelech Y. (2009). Biofloc technology: a practical guide book, B. Rouge (ed.). The World Aquaculture Society.

Avnimelech Y., Ritvo G. (2003). Shrimp and fish pond soils: Processes and management. Aquaculture, 220: 549–567.

Avnimelech Y., Kochva M., Diab S. (1994). Development of controlled intensive aquaculture systems with a limited water exchange and adjusted carbon to nitrogen ratio. Isr. J. Aquac., 46: 119–131.

Azim M.E., Little D.C. (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.

Azim M.E., Little D.C., Bron J.E. (2008). Microbial protein production in activated suspension tanks manipulating C:N ratio in feed and the implications for fish culture. Biores. Technol., 99: 3590–3599.

Azimi A., Shekarabi S.P.H., Paknejad H., Harsij M., Khorshidi Z., Zolfaghari M., Hatami A.S., Dawood M.A.O., Mazloumi N., Zakariaee H. (2022). Various carbon/nitrogen ratios in a biofloc-based rearing system of common carp (*Cyprinus carpio*) fingerlings: Effect on growth performance, immune response, and serum biochemistry. Aquaculture, 548:

737622.

Babin A., Biard C., Moret Y. (2015). Dietary supplementation with carotenoids ımproves ımmunity without ıncreasing ıts cost in a crustacean. Am. Natur., 176: 234–241.

Badiola M., Mendiola D., Bostock J. (2012). Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges. Aquac. Eng., 51: 26–35.

Bakhshi F., Najdegerami E., Manaffar R., Tokmechi A., Rahmani Farah K., Shalizar Jalali A. (2018). Growth performance, haematology, antioxidant status, immune response and histology of common carp (*Cyprinus carpio* L.) fed biofloc grown on different carbon sources. Aquac. Res., 49: 393–403.

Besen K.P., da Cunha L., Delziovo F.R., Melim E.W.H., Cipriani L.A., Gomes R., Skoronski E., Fabregat T.E.H.P. (2021). Goldfish (*Carassius auratus*) larviculture in biofloc systems: Level of *Artemia nauplii*, stocking density and concentration of the bioflocs. Aquaculture, 540: 736738.

Bossier P., Ekasari J. (2017). Biofloc technology application in aquaculture to support sustainable development goals. Microb. Biotechnol., 10: 1012–1016.

Boyd C.E., McNevin A.A. (2015). Aquaculture, resource use, and the environment. John Wiley & Sons.

Boyd C.E., D’Abramo L.R., Glencross B.D., Huyben D.C., Juarez L.M., Lockwood G.S., McNevin A.A., Tacon A.G.J., Teletchea F., Tomasso J.R., Tucker C.S., Valenti W.C. (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. J. World Aquac. Soc., 51: 578–633.

Burford M.A., Thompson P.J., McIntosh R.P., Bauman R.H., Pearson D.C. (2004). The contribution of flocculated material to shrimp (*Litopenaeus vannamei*) nutrition in a high-intensity, zero-exchange system. Aquaculture, 232: 525–537.

Cao L., Wang W., Yang Y., Yang C., Yuan Z., Xiong S., Diana J. (2007). Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. Environ. Sci. Pollut. Res. - Int., 14: 452–462.

Chen J., Liu P., Li Y., Li M., Xia B. (2018). Effects of dietary biofloc on growth, digestibility, protein turnover and energy budget of sea cucumber *Apostichopus japonicus* (Selenka). Anim. Feed Sci. Technol., 241: 151–162.

Chen X., Luo G., Tan J., Tan H., Yao M. (2020). Effects of carbohydrate supply strategies and biofloc concentrations on the growth performance of African catfish (*Clarias gariepinus*) cultured in biofloc systems. Aquaculture, 517: 734808.

Cho S.-H., Jeong J.-H., Kim M.-H., Lee K.-T., Kim D.-J., Kim K.-H., Oh S.-P., Han C.-H. (2015). The effects of temperature on maintaining the stability of water quality in biofloc-based zero-water exchange culture tanks. J. Life Sci., 25: 496–506.

Chopin T., MacDonald B., Robinson S., Cross S., Pearce C., Knowler D., Noce A., Reid G., Cooper A., Speare D., Burridge L., Crawford C., Sawhney M., Ang K.P., Backman C., Hutchinson M. (2013). La red de acuicultura multi-trófica integrada en Canadá (RAMTIC) – La red para una nueva era de acuicultura ecológicamente responsable. Fisheries, 38: 297–308.

Crab R., Chielens B., Wille M., Bossier P., Verstraete W. (2010). The effect of different carbon sources on the nutritional value of bioflocs, a feed for *Macrobrachium rosenbergii* postlarvae. Aquac. Res., 41: 559–567.

Crab R., Defoirdt T., Bossier P., Verstraete W. (2012). Biofloc technology in aquaculture: Beneficial effects and future challenges. Aquaculture, 356: 351–356.

Cullis J.D.S., Rossouw N., du Toit G., Petrie D., Wolfaardt G., de Clercq W., Horn A. (2018). Economic risks due to declining water quality in the breede river catchment. Water SA, 44: 464–473.

da Cunha L., Besen K.P., Ha N., Uczay J., Skoronski E., Fabregat T.E.H.P. (2020). Biofloc technology (BFT) improves skin pigmentation of goldfish (*Carassius auratus*). Aquaculture, 522: 735132.

da Silveira L.G.P., Krummenauer D., Poersch L.H., Rosas V.T., Wasielesky W. (2020). Hyperintensive stocking densities for *Litopenaeus vannamei* grow-out in biofloc technology culture system. J. World Aquac. Soc., 51: 1290–1300.

Das R.R., Sarkar S., Saranya C., Esakkiraj P., Aravind R., Saraswathy R., Rekha P.N., Muralidhar M., Panigrahi A. (2022). Co-culture of Indian white shrimp, *Penaeus indicus* and seaweed, *Gracilaria tenuistipitata* in amended biofloc and recirculating aquaculture system (RAS). Aquaculture, 548: 737432.

Dauda A.B., Romano N., Ebrahimi M., Teh J.C., Ajadi A., Chong C.M., Karim M., Natrah I., Kamarudin M.S. (2018). Influence of carbon/nitrogen ratios on biofloc production and biochemical composition and subsequent effects on the growth, physiological status and disease resistance of African catfish (*Clarias gariepinus*) cultured in glycerol-based biofloc systems. Aquaculture, 483: 120–130.

Dawood M.A.O. (2021). Nutritional immunity of fish intestines: important insights for sustainable aquaculture. Rev. Aquac., 13: 642–663.

Dawood M.A.O., Koshio S., Esteban M.Á. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture: a review. Rev. Aquac., 10: 950–974.

de Morais A.P.M., Abreu P.C., Wasielesky W., Krummenauer D. (2020). Effect of aeration intensity on the biofilm nitrification process during the production of the white shrimp *Litopenaeus vannamei* (Boone, 1931) in Biofloc and clear water systems. Aquaculture, 514: 734516.

De Schryver P., Crab R., Defoirdt T., Boon N., Verstraete W. (2008). The basics of bio-flocs technology: The added value for aquaculture. Aquaculture, 277: 125–137.

De Sousa A.A., Pinho S.M., Rombenso A.N., de Mello G.L., Emerenciano M.G.C. (2019). Pizzeria by-product: A complementary feed source for Nile tilapia (*Oreochromis niloticus*) raised in biofloc technology? Aquaculture, 501: 359–367.

De Souza D.M., Martins Á.C., Jensen L., Wasielesky W., Monserrat J.M., de Oliveira Garcia L. (2014 a). Effect of temperature on antioxidant enzymatic activity in the Pacific white shrimp *Litopenaeus vannamei* in a BFT (Biofloc technology) system. Marine Freshwater Behav. Physiol., 47: 1–10.

De Souza D.M., Suita S.M., Romano L.A., Wasielesky W., Ballester E.L.C. (2014 b). Use of molasses as a carbon source during the nursery rearing of *Farfantepenaeus brasiliensis* (Latreille, 1817) in a Biofloc technology system. Aquac. Res., 45: 270–277.

Deb S., Noori M.T., Rao P.S. (2020). Application of biofloc technology for Indian major carp culture (polyculture) along with water quality management. Aquac. Eng., 91: 102106.

Delgado D.L.C., Rubio C.A., Quiroz V.A.C. (2020). Proximal and sensory analysis of red tilapia (*Oreochromis* sp.) fed with fish tanks sediments from a Biofloc culture. Food Sci.

Technol., 41: 870–876.

Deng M., Chen J., Gou J., Hou J., Li D., He X. (2018). The effect of different carbon sources on water quality, microbial community and structure of biofloc systems. Aquaculture, 482: 103–110.

Diatin I., Shafruddin D., Hude N., Sholihah M., Mutsmir I. (2021). Production performance and financial feasibility analysis of farming catfish (*Clarias gariepinus*) utilizing water exchange system, aquaponic, and biofloc technology. J. Saudi Soc. Agric. Sci., 20: 344–351.

Diaz H.A.A., Ramfrez A.P.M., Emerenciano M.G.C., Carrasco S.C.P. (2021). Organoleptic and nutritional characteristics of fillets of pirapitinga fed different protein sources in a biofloc system. Pesqui. Agropecuária Bras., 55: 2020.

Ebrahimi A., Akrami R., Najdegerami E.H., Ghiasvand Z., Koohsari H. (2020). Effects of different protein levels and carbon sources on water quality, antioxidant status and performance of common carp (*Cyprinus carpio*) juveniles raised in biofloc based system. Aquaculture, 516: 734639.

Ekasari J., Hanif Azhar M., Surawidjaja E.H., Nuryati S., De Schryver P., Bossier P. (2014). Immune response and disease resistance of shrimp fed biofloc grown on different carbon sources. Fish Shellfish Immunol., 41: 332–339.

Ekasari J., Rivandi D.R., Firdausi A.P., Surawidjaja E.H., Zairin M., Bossier P., De Schryver P. (2015). Biofloc technology positively affects Nile tilapia (*Oreochromis niloticus*) larvae performance. Aquaculture, 441: 72–77.

El-Hawarry W.N., Shourbela R.M., Haraz Y.G., Khatab S.A., Dawood M.A.O. (2021). The influence of carbon source on growth, feed efficiency, and growth-related genes in Nile tilapia (*Oreochromis niloticus*) reared under biofloc conditions and high stocking density. Aquaculture, 542: 736919.

Emerenciano M., Ballester E.L.C., Cavalli R.O., Wasielesky W. (2011). Effect of biofloc technology (BFT) on the early postlarval stage of pink shrimp *Farfantepenaeus paulensis*: Growth performance, floc composition and salinity stress tolerance. Aquac. Int., 19: 891–901.

Emerenciano M., Ballester E.L.C., Cavalli R.O., Wasielesky W. (2012). Biofloc technology application as a food source in a limited water exchange nursery system for pink shrimp *Farfantepenaeus brasiliensis* (Latreille, 1817). Aquac. Res., 43: 447–457.

Emerenciano M., Cuzon G., Arévalo M., Mascaró Miquelajauregui M., Gaxiola G. (2013). Effect of short-term fresh food supplementation on reproductive performance, biochemical composition, and fatty acid profile of *Litopenaeus vannamei* (Boone) reared under biofloc conditions. Aquac. Int., 21: 987–1007.

FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action.

FAO (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. FAO.

Ferreira G.S., Bolívar N.C., Pereira S.A., Guertler C., do Nascimento Vieira F., Mouriño J.L.P., Seiffert W.Q. (2015). Microbial biofloc as source of probiotic bacteria for the culture of *Litopenaeus vannamei*. Aquaculture, 448: 273–279.

Fleckenstein L.J., Tierney T.W., Ray A.J. (2018). Comparing biofloc, clear-water, and hybrid recirculating nursery systems (Part II): Tilapia (*Oreochromis niloticus*) production and water quality dynamics. Aquac. Eng., 82: 80–85.

Fóes G.K., Fróes C., Krummenauer D., Poersch L., Wasielesky W. (2011). Nursery of pink shrimp farfantepenaeus paulensis in biofloc technology culture system: survival and growth at different stocking densities. J. Shellfish Res., 30: 367–373.

Frankic A., Hershner C. (2003). Sustainable aquaculture: Developing the promise of aquaculture. Aquac. Int., 11: 517–530.

Furtado P.S., Campos B.R., Serra F.P., Klosterhoff M., Romano L.A., Wasielesky W. (2015). Effects of nitrate toxicity in the Pacific white shrimp, *Litopenaeus vannamei*, reared with biofloc technology (BFT). Aquac. Int., 23: 315–327.

Gaona C.A.P., Poersch L.H., Krummenauer D., Foes G.K., Wasielesky W.J. (2011). The effect of solids removal on water quality, growth and survival of *Litopenaeus vannamei* in a biofloc technology culture system. Int. J. Recirc. Aquac., 12.

Gaona C.A.P., da Paz Serra F., Furtado P.S., Poersch L.H., Wasielesky W. (2016). Effect of different total suspended solids concentrations on the growth performance of *Litopenaeus vannamei* in a BFT system. Aquac. Eng., 72–73: 65–69.

Gaona C.A.P., de Almeida M.S., Viau V., Poersch L.H., Wasielesky W. (2017). Effect of different total suspended solids levels on a *Litopenaeus vannamei* (Boone, 1931) BFT culture system during biofloc formation. Aquac. Res., 48: 1070–1079.

Goldman J.C., Caron D.A., Dennett M.R. (1987). Regulation of gross growth efficiency and ammonium regeneration in bacteria by substrate C: N ratio. Limnol. Oceanogr., 32: 1239–1252.

Gutierrez-Wing M.T., Malone R.F. (2006). Biological filters in aquaculture: Trends and research directions for freshwater and marine applications. Aquac. Eng., 34: 163–171.

Hargreaves J.A. (2006). Photosynthetic suspended-growth systems in aquaculture. Aquac. Eng., 34: 344–363.

Hargreaves J.A. (2013). Biofloc production systems for aquaculture. South. Reg. Aquac. Cent., 4503.

Harun A.A.C., Mohammad N.A.H., Ikhwanuddin M., Jauhari I., Sohaili J., Kasan N.A. (2019). Effect of different aeration units, nitrogen types and inoculum on biofloc formation for improvement of Pacific Whiteleg shrimp production. Egypt. J. Aquat. Res., 45: 287–292.

Hoang M.N., Nguyen P.N., Bossier P. (2020). Water quality, animal performance, nutrient budgets and microbial community in the biofloc-based polyculture system of white shrimp, *Litopenaeus vannamei* and gray mullet, *Mugil cephalus*. Aquaculture, 515: 734610.

Hollender J., Van der Krol D., Kornberger L., Gierden E., Dott W. (2002). Effect of different carbon sources on the enhanced biological phosphorus removal in a sequencing batch reactor. World J. Microbiol. Biotechnol., 18: 355–360.

Hostins B., Braga A., Lopes D.L.A., Wasielesky W., Poersch L.H. (2015). Effect of temperature on nursery and compensatory growth of pink shrimp *Farfantepenaeus brasiliensis* reared in a super-intensive biofloc system. Aquac. Eng., 66: 62–67.

Hostins B., Wasielesky W., Decamp O., Bossier P., De Schryver P. (2019). Managing input C/N ratio to reduce the risk of Acute Hepatopancreatic Necrosis Disease (AHPND) outbreaks in biofloc systems – A laboratory study. Aquaculture, 508: 60–65.

Huerta-Rábago J.A., Martínez-Porchas M., Miranda-Baeza A., Nieves-Soto M., Rivas-Vega M.

E., Martínez-Córdova L.R. (2019). Addition of commercial probiotic in a biofloc shrimp farm of *Litopenaeus vannamei* during the nursery phase: Effect on bacterial diversity using massive sequencing 16S rRNA. Aquaculture, 502: 391–399.

Hussain A., Ali E., Sallam W., Hussain A.S., Mohammad D.A., Ali E.M., Sallam W.S. (2015). Growth Performance of the green tiger shrimp *Penaeus semisulcatus* raised in biofloc systems air quality modelling view project. J. Aquac. Mar. Biol., 2.

Kamilya D., Debbarma M., Pal P., Kheti B., Sarkar S., Singh S.T. (2017). Biofloc technology application in indoor culture of *Labeo rohita* (Hamilton, 1822) fingerlings: The effects on inorganic nitrogen control, growth and immunity. Chemosphere, 182: 8–14.

Kathia C.M., Carmen M.D., Aida H.P., Jorgey C.M., Daniel B.-C. (2017). Probiotics used in Biofloc system for fish and crustacean culture: A review. Int. J. Fish. Aquat. Stud., 5: 120–125.

Kaya D., Genc M.A., Aktas M., Eroldogan O.T., Aydin F.G., Genc E. (2019 a). Effects of Biofloc Technology (BFT) on Growth of Speckled Shrimp (*Metapenaeus monoceros*). Tarım Bilim. Derg., 25: 491–497.

Kaya D., Genc M.A., Aktas M., Yavuzcan H., Ozmen O., Genc E. (2019 b). Effect of biofloc technology on growth of speckled shrimp, *Metapenaeus monoceros* (Fabricus) in different feeding regimes. Aquac. Res., 50: 2760–2768.

Khanjani M.H., Sharifinia M. (2020). Biofloc technology as a promising tool to improve aquaculture production. Rev. Aquac., 12: 1836–1850.

Khatoon H., Banerjee S., Guan Yuan G.T., Haris N., Ikhwanuddin M., Ambak M.A., Endut A. (2016). Biofloc as a potential natural feed for shrimp postlarvae. Int. Biodeterior. Biodegrad., 113: 304–309.

Kim S.K., Guo Q., Jang I.K. (2015). Effect of biofloc on the survival and growth of the postlarvae of three penaeids (*Litopenaeus Vannamei, Fenneropenaeus Chinensis, and Marsupenaeus Japonicus*) and their biofloc feeding efficiencies, as related to the morphological structure of the third maxilliped. J. Crustac. Biol., 35: 41–50.

Kim S.K., Jang I.K., Kim S.R., Jeon J.C., Kim S.K. (2021). Effects of artificial substrates on the growth and immunology of postlarvae of *Marsupenaeus japonicus* (Spence Bate, 1888) (Decapoda: Dendrobranchiata: Penaeidae) reared in biofloc. J. Crustac. Biol., 41: ruab044.

Krummenauer D., Peixoto S., Cavalli R.O., Poersch L.H., Wasielesky W. (2011). Superintensive culture of white shrimp, *Litopenaeus vannamei*, in a biofloc technology system in Southern Brazil at different stocking densities. J. World Aquac. Soc., 42: 726–733.

Krummenauer D., Samocha T., Poersch L., Lara G., Wasielesky W. (2014). The reuse of water on the culture of pacific white shrimp, l*itopenaeus vannamei*, in BFT system. J. World Aquac. Soc., 45: 3–14.

Kuhn D.D., Lawrence A.L., Boardman G.D., Patnaik S., Marsh L., Flick G.J. (2010). Evaluation of two types of bioflocs derived from biological treatment of fish effluent as feed ingredients for Pacific white shrimp, *Litopenaeus vannamei*. Aquaculture, 303: 28–33.

Kumar S.V., Pandey P.K., Anand T., Bhuvaneswari G.R., Dhinakaran A., Kumar S. (2018). Biofloc improves water, effluent quality and growth parameters of *Penaeus vannamei* in an intensive culture system. J. Environ. Manage., 215: 206–215.

Kumari S., Harikrishna V., Surasani V.K.R., Balange A.K., Babitha Rani A.M. (2021). Growth, biochemical indices and carcass quality of red tilapia reared in zero water discharge based biofloc system in various salinities using inland saline ground water. Aquaculture, 540: 736730.

Kurtoğlu İ.Z., Ak K., Genç S. (2021). Effects of stocking density during live transportation on haematological parameters of Siberian sturgeon (*Acipenser baerii*, Brandt, 1869). J. Appl. Ichthyol., 37: 809–815.

Laice L.M., Corrêa Filho R.A.C., Ventura A.S., Farias K.N.N., do Nascimento Silva A.L., Fernandes C.E., Silva A.C.F., Barbosa P.T.L., de Souza A.I., Emerenciano M.G.C., Povh J.A. (2021). Use of symbiotics in biofloc (BFT)-based Nile tilapia culture: Production performance, intestinal morphometry and hematological parameters. Aquaculture, 530: 735715.

Lara G., Hostins B., Bezerra A., Poersch L., Wasielesky W. (2017 a). The effects of different feeding rates and re-feeding of *Litopenaeus vannamei* in a biofloc culture system. Aquac. Eng., 77: 20–26.

Lara G., Krummenauer D., Abreu P.C., Poersch L.H., Wasielesky W. (2017 b). The use of different aerators on *Litopenaeus vannamei* biofloc culture system: effects on water quality, shrimp growth and biofloc composition. Aquac. Int., 25: 147–162.

Liang W., Luo G., Tan H., Ma N., Zhang N., Li L. (2014). Efficiency of biofloc technology in suspended growth reactors treating aquacultural solid under intermittent aeration. Aquac. Eng., 59: 41–47.

Lim L.C., Dhert P., Sorgeloos P. (2003). Recent developments in the application of live feeds in the freshwater ornamental fish culture. Aquaculture, 227: 319–331.

Lim Y.S., Ganesan P., Varman M., Hamad F.A., Krishnasamy S. (2021). Effects of microbubble aeration on water quality and growth performance of *Litopenaeus vannamei* in biofloc system. Aquac. Eng., 93: 102159.

Lima P.C.M., Abreu J.L., Silva A.E.M., Severi W., Galvez A.O., Brito L.O. (2018). Nile tilapia fingerling cultivated in a low-salinity biofloc system at different stocking densities. Spanish J. Agric. Res., 16: e0612–e0612.

Liu G., Ye Z., Liu D., Zhao J., Sivaramasamy E., Deng Y., Zhu S. (2018). Influence of stocking density on growth, digestive enzyme activities, immune responses, antioxidant of *Oreochromis niloticus* fingerlings in biofloc systems. Fish Shellfish Immunol., 81: 416–422.

Liu H., Li H., Wei H., Zhu X., Han D., Jin J., Yang Y., Xie S. (2019). Biofloc formation improves water quality and fish yield in a freshwater pond aquaculture system. Aquaculture, 506: 256–269.

Luo G., Gao Q., Wang C., Liu W., Sun D., Li L., Tan H. (2014). Growth, digestive activity, welfare, and partial cost-effectiveness of genetically improved farmed tilapia (*Oreochromis niloticus*) cultured in a recirculating aquaculture system and an indoor biofloc system. Aquaculture, 422–423: 1–7.

Luo G., Liu Z., Shao L., Tan H. (2019). Using poly-β-hydroxybutyric as an additional carbohydrate for biofloc in a shrimp *Litopenaeus vannamei* bioflocs nursery system with brackish water. Aquaculture, 506: 181–187.

Mahanand S.S., Moulick S., Rao P.S. (2013). Water quality and growth of rohu, *Labeo rohita*, in a biofloc system. J. Appl. Aquac., 25: 121–131.

Mansour A.T., Esteban M.Á. (2017). Effects of carbon sources and plant protein levels in a biofloc system on growth performance, and the immune and antioxidant status of Nile tilapia (*Oreochromis niloticus*). Fish Shellfish Immunol., 64: 202–209.

Manzoor P.S., Rawat K.D., Tiwari V.K., Poojary N., Asanaru Majeedkutty B.R. (2020). Dietary lipid influences gonadal maturation, digestive enzymes and serum biochemical indices of *Cyprinus carpio* reared in biofloc system. Aquac. Res., 51: 3244–3254.

Martinez-Porchas M., Ezquerra-Brauer M., Mendoza-Cano F., Chan-Higuera J.E., Vargas-Albores F., Martinez-Cordova L.R. (2020). Effect of supplementing heterotrophic and photoautotrophic biofloc, on the production response, physiological condition and post-harvest quality of the whiteleg shrimp, *Litopenaeus vannamei.* Aquac. Reports, 16: 100257.

Martins C.I.M., Eding E.H., Verdegem M.C.J., Heinsbroek L.T.N., Schneider O., Blancheton J.P., d'Orbcastel E.R., Verreth J.A.J. (2010). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Aquac. Eng., 43: 83–93.

Megahed M.E. (2010). The effect of microbial biofloc on water quality, survival and growth of the green tiger shrimp (*Penaeus Semisulcatus*) fed with different crude protein levels. J. Arab. Aquac. Soc., 5: 119–142.

Menaga M., Felix S., Charulatha M., Gopalakannan A., Panigrahi A. (2019). Effect of in-situ and ex-situ biofloc on immune response of genetically improved farmed Tilapia. Fish Shellfish Immunol., 92: 698–705.

Minaz M., Kubilay A. (2021). Operating parameters affecting biofloc technology: carbon source, carbon/nitrogen ratio, feeding regime, stocking density, salinity, aeration, and microbial community manipulation. Aquac. Int., 29: 1121–1140.

Minaz M., Ak K., Kurtoğlu İ.Z. (2021). Occupational health and safety risk analysis in trout aquaculture facility. OHS Acad. İş Sağlığı ve Güvenliği Akad. Derg., 4: 14–21.

Najdegerami E.H., Bakhshi F., Lakani F.B. (2016). Effects of biofloc on growth performance, digestive enzyme activities and liver histology of common carp (*Cyprinus carpio* L.) fingerlings in zero-water exchange system. Fish Physiol. Biochem., 42: 457–465.

Naylor R.L., Goldburg R.J., Primavera J.H., Kautsky N., Beveridge M.C.M., Clay J., Folke C., Lubchenco J., Mooney H., Troell M. (2000). Effect of aquaculture on world fish supplies. Nature, 405: 1017–1024.

Oehmen A., Yuan Z., Blackall L.L., Keller J. (2004). Short-term effects of carbon source on the competition of polyphosphate accumulating organisms and glycogen accumulating organisms. Water Sci. Technol., 50: 139–144.

Panigrahi A., Saranya C., Sundaram M., Vinoth Kannan S.R., Das R.R., Satish Kumar R., Rajesh P., Otta S.K. (2018). Carbon: Nitrogen (C:N) ratio level variation influences microbial community of the system and growth as well as immunity of shrimp (*Litopenaeus vannamei*) in biofloc based culture system. Fish Shellfish Immunol., 81: 329–337.

Panigrahi A., Sundaram M., Saranya C., Swain S., Dash R.R., Dayal J.S. (2019). Carbohydrate sources deferentially influence growth performances, microbial dynamics and immunomodulation in Pacific white shrimp (*Litopenaeus vannamei*) under biofloc system. Fish Shellfish Immunol., 86: 1207–1216.

Panigrahi A., Das R.R., Sivakumar M.R., Saravanan A., Saranya C., Sudheer N.S., Kumaraguru Vasagam K.P., Mahalakshmi P., Kannappan S., Gopikrishna G. (2020 a). Bio-augmentation of heterotrophic bacteria in biofloc system improves growth, survival, and immunity of Indian white shrimp *Penaeus indicus*. Fish Shellfish Immunol., 98: 477–487.

Panigrahi A., Sivakumar M.R., Sundaram M., Saravanan A., Das R.R., Katneni V.K., Ambasankar K., Syama Dayal J., Gopikrishna G. (2020 b). Comparative study on phenoloxidase activity of biofloc-reared pacific white shrimp *Penaeus vannamei* and Indian white shrimp P*enaeus indicu*s on graded protein diet. Aquaculture, 518: 734654.

Panigrahi A., Esakkiraj P., Das R.R., Saranya C., Vinay T.N., Otta S.K., Shekhar M.S. (2021). Bioaugmentation of biofloc system with enzymatic bacterial strains for high health and production performance of *Penaeus indicus*. Sci. Rep., 11: 1–13.

Pérez-Fuentes J.A., Hernández-Vergara M.P., Pérez-Rostro C.I., Fogel I. (2016). C:N ratios affect nitrogen removal and production of Nile tilapia *Oreochromis niloticus* raised in a biofloc system under high density cultivation. Aquaculture, 452: 247–251.

Piedrahita R.H. (2003). Reducing the potential environmental impact of tank aquaculture effluents through intensification and recirculation. Aquaculture, 226: 35–44.

Pinho S.M., Emerenciano M.G.C. (2021). Sensorial attributes and growth performance of whiteleg shrimp (*Litopenaeus vannamei*) cultured in biofloc technology with varying water salinity and dietary protein content. Aquaculture, 540: 736727.

Ponce-Palafox J.T., Pavia Á.A., Mendoza López D.G., Arredondo-Figueroa J.L., Lango-Reynoso F., Castañeda-Chávez M. del R., Esparza-Leal H., Ruiz-Luna A., Páez-Ozuna F., Castillo-Vargasmachuca S.G., Peraza-Gómez V. (2019). Response surface analysis of temperature-salinity interaction effects on water quality, growth and survival of shrimp *Penaeus vannamei* postlarvae raised in biofloc intensive nursery production. Aquaculture, 503: 312–321.

Putra I., Rusliadi R., Fauzi M., Tang U.M., Muchlisin Z.A. (2017). Growth performance and feed utilization of African catfish *Clarias gariepinus* fed a commercial diet and reared in the biofloc system enhanced with probiotic. F1000Res., 6: 1545.

Qiao G., Zhang M., Li Y., Xu C., Xu D. H., Zhao Z., Zhang J., Li Q. (2018). Biofloc technology (BFT): An alternative aquaculture system for prevention of Cyprinid herpesvirus 2 infection in gibel carp (*Carassius auratus gibelio*). Fish Shellfish Immunol., 83: 140–147.

Romano N., Dauda A.B., Ikhsan N., Karim M., Kamarudin M.S. (2018). Fermenting rice bran as a carbon source for biofloc technology improved the water quality, growth, feeding efficiencies, and biochemical composition of African catfish Clarias gariepinus juveniles. Aquac. Res., 49: 3691–3701.

Romero J., Feijoo C.G., Navarrete P. (2012). Antibiotics in aquaculture – use, abuse and alternatives. In: Health and environment in aquaculture, Carvalho E. (ed.). IntechOpen, pp. 159–198.

Roques S., Deborde C., Richard N., Skiba-Cassy S., Moing A., Fauconneau B. (2020). Metabolomics and fish nutrition: a review in the context of sustainable feed development. Rev. Aquac., 12: 261–282.

Schneider O., Sereti V., Eding E.H., Verreth J.A.J. (2005). Analysis of nutrient flows in integrated intensive aquaculture systems. Aquac. Eng., 32: 379–401.

Schveitzer R., Arantes R., Costódio P.F.S., do Espírito Santo C.M., Arana L.V., Seiffert W.Q., Andreatta E.R. (2013). Effect of different biofloc levels on microbial activity, water quality and performance of *Litopenaeus vannamei* in a tank system operated with no water exchange. Aquac. Eng., 56: 59–70.

Seixas S., Saravanan S., Gonçalves S. (2015). Innovation and educational changes: two e-Learning cases in aquaculture. Aquac. Int., 23: 843–859.

Sgnaulin T., Pinho S.M., Durigon E.G., Thomas M.C., de Mello G.L., Emerenciano M.G.C. (2021). Culture of pacu Piaractus mesopotamicus in biofloc technology (BFT): insights on dietary protein sparing and stomach content. Aquac. Int., 29: 2319–2335.

Sharifinia M., Taherizadeh M., Namin J.I., Kamrani E. (2018). Ecological risk assessment of trace metals in the surface sediments of the Persian Gulf and Gulf of Oman: Evidence from subtropical estuaries of the Iranian coastal waters. Chemosphere, 191: 485–493.

Silva T.S., Piana P.A. (2020). Production of tilapia in biofloc with different salt condictions: An evaluation of body composition and organoleptic properties. Bol. Do Inst. Pesca, 46.

Souza R.L. de, Lima E.C.R. de, Melo F.P. de, Ferreira M.G.P., Correia E. de S. (2019). The culture of Nile tilapia at different salinities using a biofloc system. Rev. Ciência Agronômica, 50.

Sutthi N., Thaimuangphol W., Rodmongkoldee M., Leelapatra W., Panase P. (2018). Growth performances, survival rate, and biochemical parameters of Nile tilapia (*Oreochromis niloticus*) reared in water treated with probiotic. Comp. Clin. Pathol., 27: 597–603.

Tabarrok M., Seyfabadi J., Salehi Jouzani G., Younesi H. (2020). Comparison between recirculating aquaculture and biofloc systems for rearing juvenile common carp (*Cyprinus carpio*): Growth performance, haemato-immunological indices, water quality and microbial communities. Aquac. Res., 51: 4881–4892.

Taw N. (2010). Biofloc technology expanding at white shrimp farms. Glob. Aquac. Advocate, 20–22.

Timmonsand M., Ebeling J.M. (2010). Recirculating aquaculture, 2nd ed. (Cayuga Aqua Ventures). Ithaca.

Touiri L., Najjar F. . Z., Rolle F., Crespi V. (2020). Aquaculture capacity development in morocco through the establishment of an aquaculture demonstration center for the training of qualified personnel. FAO Aquac. Newsl., 62: 32–34.

Turcios A.E., Papenbrock J. (2014). Sustainable treatment of aquaculture effluents-What can we learn from the past for the future? Sustain., 6: 836–856.

Vadhel N., Pathan J., Shrivastava V., Akolkar N., Kumar S., Misra C.K., Das Mahapatra K. (2020). Comparative study on the performance of genetically improved rohu "Jayanti" and native rohu, *Labeo rohita* fingerlings reared in biofloc system. Aquaculture, 523: 735201.

Valderrama D., Hishamunda N., Zhou X. (2010). Estimating employment in world aquaculture. FAO Aquac. Newsl., 24–25.

Van Doan H., Lumsangkul C., Hoseinifar S.H., Jaturasitha S., Tran H.Q., Chanbang Y., Ringø E., Stejskal V. (2022). Influences of spent coffee grounds on skin mucosal and serum immunities, disease resistance, and growth rate of Nile tilapia (*Oreochromis niloticus*) reared under biofloc system. Fish Shellfish Immunol., 120: 67–74.

Vasava R., Hodar A.R., Elchelwar V.R., Deepak A.P., Patel K.M., Shrivastava V., Yusufzai

S.I., Acharya P., Prabhakar P. (2020). Biofloc technology: An innovative approach to zero-water exchange and tentative zero-feed system: A review. J. Entomol. Zool. Stud., 8: 1036–1040.

Vinatea L., Malpartida J., Carbó R., Andree K.B., Gisbert E., Estévez A. (2018). A comparison of recirculation aquaculture systems versus biofloc technology culture system for on-growing of fry of *Tinca tinca* (Cyprinidae) and fry of grey Mugil cephalus (Mugilidae). Aquaculture, 482: 155–161.

Waite R., Beveridge M., Brummett R., Castine S., Chaiyawannakarn N., Kaushik S., Mungkung R., Nawapakpilai S., Phillips M. (2014). Improving productivity and environmental performance of aquaculture. WorldFish.

Wang C., Pan L., Zhang K., Xu W., Zhao D., Mei L. (2016). Effects of different carbon sources addition on nutrition composition and extracellular enzymes activity of bioflocs, and digestive enzymes activity and growth performance of Litopenaeus vannamei in zero-exchange culture tanks. Aquac. Res., 47: 3307–3318.

Wang G., Yu E., Xie J., Yu D., Li Z., Luo W., Qiu L., Zheng Z. (2015). Effect of C/N ratio on water quality in zero-water exchange tanks and the biofloc supplementation in feed on the growth performance of crucian carp, *Carassius auratus*. Aquaculture, 443: 98–104.

Webster C.D., Lim C.E. (2002). Nutrient requirements and feeding of finfish for aquaculture. CABI.

Wei Y.F., Liao S.A., Wang A. (2016). The effect of different carbon sources on the nutritional composition, microbial community and structure of bioflocs. Aquaculture, 465: 88–93.

Wilén B.M., Lund Nielsen J., Keiding K., Nielsen P.H. (2000). Influence of microbial activity on the stability of activated sludge flocs. Coll. Surf. B Biointerfaces, 18: 145–156.

World Bank. (2013). Fish to 2030: Prospects for Fisheries and Aquaculture.

Xu W.J., Pan L.Q. (2013). Enhancement of immune response and antioxidant status of Litopenaeus vannamei juvenile in biofloc-based culture tanks manipulating high C/N ratio of feed input. Aquaculture, 412–413: 117–124.

Xu W.J., Morris T.C., Samocha T.M. (2016). Effects of C/N ratio on biofloc development, water quality, and performance of Litopenaeus vannamei juveniles in a biofloc-based, high-density, zero-exchange, outdoor tank system. Aquaculture, 453: 169–175.

Yazıcı İ.S., Hisar O., Yilmaz S., Yiğit M. (2015). Effects of different probiotic bacteria on growth, body composition, immune response and hematological parameters of rainbow trout (*Oncorhynchus mykiss*) under sublethal water temperature. Mar. Sci. Technol. Bull., 4: 21–28.

Yu Z., Li L., Zhu R., Li M., Duan J., Wang J. Y., Liu Y. H., Wu L. F. (2020). Monitoring of growth, digestive enzyme activity, immune response and water quality parameters of Golden crucian carp (*Carassius auratus*) in zero-water exchange tanks of biofloc systems. Aquac. Rep., 16: 100283.

Zhang N., Luo G., Tan H., Liu W., Hou Z. (2016). Growth, digestive enzyme activity and welfare of tilapia (*Oreochromis niloticus*) reared in a biofloc-based system with poly-β-hydroxybutyric as a carbon source. Aquaculture, 464: 710–717.

Zhao F., Yang W., Zeng Z., Li H., Yang X., He Z., Gu B., Rafiq M. T., Peng H. (2012). Nutrient removal efficiency and biomass production of different bioenergy plants in hypereutrophic water. Biomass Bioenergy, 42: 212–218.

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