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Polyculture of Genetically Improved Farmed Tilapia (GIF Tilapia) and *Penaeus vannamei* using Biofloc Technology–A Review

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ABSTRACT

According to Food and Agriculture Organization of the United Nations (FAO), aquaculture has grown faster and its expansion aimed at meeting the increase of world fish demand, and preserving natural fish stocks. Currently, to produce fish in quantity and quality requires reduction of the environmental impact from aquaculture, through the improvement of culture systems. Disease is the major factor affecting the development and expansion in aquaculture. Losses due to disease in shrimp farming are high. Various approaches to minimize the impact of disease on production are possible. Another approach to keep the pathogen pressure low is polyculture of shrimp and finfish. This practice makes shrimp farming more sustainable by reducing the environmental impact and the incidence of shrimp disease. Antimicrobial peptides in the fish skin kill shrimp pathogens, keeping pathogen pressure of bacteria and viruses low. In polyculture, shrimps can eat tilapia faeces and unused fish feed, while tilapia filter phytoplankton, reducing the risk of low dissolved oxygen levels at night. In addition, shrimp bioturbation at the pond bottom returns nutrients to the water column, enhancing phytoplankton production and consequently the natural feed available for the tilapia. Biofloc technology (BFT) is one of the most applicable and promising systems for sustainable aquaculture development. This technology is essentially based on the recycling of nutrients via microorganisms, primarily (i) heterotrophic bacteria, which convert nitrogen compounds into microbial biomass, in addition to serves as a source of food for aquatic organisms, and (ii) chemoautotrophic bacteria, which convert ammonia to nitrite and nitrate.

KEYWORDS: Aquaculture, biofloc, fisheries, polyculture, sustainability

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1. INTRODUCTION

Aquaculture is one of the fastest growing sectors of animal protein production in the world, contributing to the global food security and nutrition in the twenty-first century. Fisheries and aquaculture not only provide livelihood, but also offer dietary essentials for human consumption (Ngasotter et al., 2020). India ranks second in the world for aquaculture production due to its abundance of fisheries resources, making it the third-largest fish-producing nation globally with 7.96% of total production.

Aquaculture animals usually retain 20–25% of protein in the feed, while the rest discharged as ammonia and organic nitrogen in feed residues and excrement (Crab et al., 2007; Piedrahita, 2003), resulting in water deterioration disease outbreaks and heavy financial loss (Samocha et al., 2004; Avnimelech, 2006; Azim and Little, 2008). Another major constraint in the aquaculture industry is to find alternative primary sources of fish meal and fish oil as important and expensive valuable protein and oil sources in the aquaculture-formulated diet (Zhu et al., 2010). Therefore, alternative strategies should be investigated to make the aquaculture industry more sustainable and profitable. To overcome the environmental damage and increase sustainable aquaculture production (Avnimelech, 2009), one of the promising technologies that developed was an ecofriendly culture technology known as biofloc technology (Martínez-Córdova et al., 2017).

The interactions between aquatic farmed organisms in polyculture are mostly determined by the species' biological traits and the stocking densities employed. Improvements in food availability and environmental conditions are major synergistic interactions (Milstein, 1992) in polyculture. Conversely, agonistic behavior and competition for food, space, oxygen, transmission of pathogens and other resources inside the growout unit are the main antagonistic interactions. Therefore, the secret to a successful polyculture is to use ecologically distinct species with complimentary requirements and to arrange a proper stocking density for each.

Among the various shrimp species, *Penaeus vannamei* was the top species produced in 2020. Shrimp are basically benthic and omnivore feeding on detritus, algal films, and bacteria (D'Abramo and New, 2000). *Penaeus vannamei* has a consolidated and expanding producing chain, due to its high feed conversion ratio, disease resistance and can thrive in varying water conditions. This makes it an economically viable option for farmers as it maximizes production and reduces costs. Polyculture involving *Penaeus vannamei* helps to optimize resource utilization, as different species have different feeding habits and occupy different niches within the ecosystem. This can result in increased productivity, improved water quality, and enhanced overall sustainability of the aquaculture system.

Tilapia is the widely grown fish on earth after carps, and the most prolific species grown in aquaculture. GIF Tilapia is basically pelagic (Wang and Lu, 2015) and omnivorous, filtering phytoplankton (Perschbacher and Lorio, 1993) and feeding on periphyton (Azim et al., 2004). GIF Tilapia was chosen because of its many desirable attributes including short generation interval, importance in developing countries, hardiness, feeding habits, resistance to diseases and general suitability of farming systems. Tilapia has proven to be ideal species for polyculture (Yakupitiyage et al., 1991).

Shrimp and GIF tilapia match the fundamentals described above, mainly because of diverse feeding habits and spatial distribution; they may be raised in the same pond due to separate environmental niches. In polyculture, shrimp can consume leftover fish food and waste, and fish can filter phytoplankton (Perschbacher and Lorio, 1993), which lowers the danger of low dissolved oxygen levels at night times (Santos and Valenti, 2002). Moreover, shrimp bioturbation at the pond's bottom also recycles nutrients into the water column (Kimpara et al., 2011), which increase the phytoplankton production, a natural food for fish.

2. FISHERIES AND AQUACULTURE SCENARIO

The fisheries and aquaculture sectors have been increasingly recognized for their essential contribution to global food security and nutrition in the twenty-first century (Verdegem et al., 2023). With 811 million people suffering from hunger and 3 billion people not able to afford healthy diets, the world is far from its proclaimed goal of ending hunger and malnutrition in all its forms by 2030 (Kakaei et al., 2022). Aquaculture not only supplies dietary essentials for human consumption (Jayasankar, 2018), but provide livelihoods to around 820 million people worldwide (Ngasotter et al., 2020). India is bestowed with an abundance of fisheries resources with 3.15 million ha of reservoirs, 2.36 million ha of ponds and tanks as well as 0.19 million ha of rivers and canals (Handbook, 2019; Datta, 2011). India is the third largest fish producing country, contributing 8% to the global fish production and ranks second in aquaculture production. The fisheries and aquaculture production contributes around 1% to India's Gross Domestic Product (GDP) and over 5% to the agricultural GDP. Global aquaculture production retained its growth trend in 2020 amid the worldwide spread of the COVID-19 pandemic. The total aquaculture production comprises 87.5 mt of aquatic animals, 35.1 mt of algae, 700 tonnes of shells and pearls, reaching a total of 122.6 mt in live weight in 2020. This represents an increase of 6.7 mt from 115.9 mt in 2018. World aquaculture production of animal species grew by 2.7% in 2020 compared with 2019, an all-time low rate of annual growth in over 40 years. In 2020, farmed finfish reached 57.5 mt, including 49.1 mt from inland aquaculture and 8.3 mt from Mariculture in the sea and coastal aquaculture on the shore. Production of other farmed aquatic animal species reached 17.7 mt of molluscs mostly bivalves, 11.2 mt of crustaceans. Global apparent consumption of aquatic foods increased at an average annual rate of 3.0% from 1961 to 2019, a rate almost twice that of annual world population growth (1.6%) for the same period. Per capita consumption of aquatic animal foods grew by about 1.4% $year^{-1}$, from 9.0 kg in 1961 to 20.2 kg in 2020.

3. PROBLEMS OF AQUACULTURE

Aquaculture is the culture of aquatic organisms. People have been involved in different forms of aquaculture for thousands of years. Today, the practice of aquaculture spans the globe. Many of the basic goals have not changed significantly in aquaculture: maximizing growth rate and minimizing production cost. A rapid growth rate minimizes the time to achieve a marketable size and decreases risk. The reduction of production costs makes an operation profitable. To accomplish this, there are number of strategies such as maximizing food conversion and reducing water and land use. Farming requires high protein diets to maintain productivity (Attasat et al., 2013). The downside is the production of a large quantity of nitrogenous and phosphorous waste (Yi et al., 2002). Most nutrients are derived from feed of which only 24–37% and 13–28% of nitrogen and phosphorous, respectively are converted into biomass, while the rest was being lost as organic nitrogen and ammonia in faeces and feed residue (Samocha et al., 2004; Lawrence et al., 2001). This leads to water deterioration, disease outbreaks and heavy financial loss (Azim and Little, 2008; Avnimelech, 2006). A high water exchange frequency is needed to maintain a good pond water quality, displacing the waste into receiving ecosystems (Attasat et al., 2013). The environmental impact of untreated effluents has raised concerns about the sustainability of farming. Another important constraint is the increasing pressure to find alternative primary sources of fish meal and fish oil as important and expensive valuable protein and oil sources in an aquaculture formulated diet (Zhu et al., 2010).

4. SOLUTIONS TO MITIGATE THE PROBLEMS OF AQUACULTURE SECTOR

Major difficulties challenged by aquaculture industry are effluent discharge, feed cost and water. To mitigate the above mentioned problems, advanced aquaculture technologies can be adopted. Hence to sustain the production and safeguard the environment, new technologies like biofloc (Avnimelech, 1999), polyculture (Jhingran, 1975), raceway technology (Felix, 2006), and aerated lined pond (Felix, 2012) can be applied.

4.1. *Biofloc technology*

Biofloc technology (BFT) is an innovative and sustainable method of fish production technique that has been recently received a lot of attention at global level. It entails the aquaculture system's growth by its dense microbial communities, known as biofloc (Yu et al., 2023). Biofloc is known to prevent accumulation of toxic nitrogen metabolites (NH_3 and NO_2^-, etc.) by stimulating and manipulating the carbon/nitrogen ratio (C/N) and converting the metabolites into microbial flocs, even in a zero-water exchange system (Avnimelech et al., 1994; Mc Intosh, 2000). The microbial flocs are formed by heterotrophic bacteria, phytoplankton, zooplankton and protozoa (Avnimelech, 2007). Biofloc technology is an economical alternative for use in decreasing the commercial diets of fish, while simultaneously reducing potential environmental problems (Bauer et al., 2012). The use of biofloc technology has several advantages over other conventional fish farming technologies such as better water quality (Megahed, 2010), disease prevention, lower feed costs, and minimized environmental effect (Naylor et al., 2000).

4.2. *Polyculture*

Polyculture is a traditional fish farming practice; where compatible species with different feeding habits were stocked in a single-pond for grow out practice to effectively increase production (Zimmermann & New, 2000; Jhingran, 1975). The idea of polyculture is based on the principle that each species stocked has its own ecological and feeding niche that doesn't completely overlap with feeding niches of other species. In monoculture practices, the excess nutrients from uneaten food increase the phytoplankton and ammonia concentrations and change the dissolved oxygen dynamics (Midlen and Redding, 1998). Polyculture adds a subordinate species and improves the performance of the cultured species by enhancing water quality (Wang et al., 1998; Tian et al., 2001). Therefore, polyculture fits the principle of sustainable aquaculture; reduces the impact on environment, increase profitability, provides benefits associated with advanced ecological stability and function by optimizing use of available resources (Wohlfarth et al., 1885; McKinnon et al., 2002).

4.3. *Raceway culture system*

A raceway is a channel with a continuous flow of water constructed for high density aquatic organism production. The aquaculture term "raceway" is a highly generic name and implies little more than a water impoundment with water flowing through it (Stuart et al., 2009). The Romans and perhaps even earlier cultures-used complex water management systems to effectively create and manage both aquaculture raceway and static pond system (Wyban et al., 1991). They are usually oval tanks (or polygonal tanks with rounded corners as per Taiwanese shrimp industry of the 1980's) of medium depth and whose diameter is a function of the velocity of the water flow (Shigueno, 1975). The water flow velocity is then a compromise between the flow tolerances of the aquaculture species used and the hydrodynamic characteristics of their waste (Costa Pierce and Barry, 2005). Raceway removes the solids and dissolved waste from the culture unit on a continuous basis, which reduces the discharge of effluent into the environment (Rakocy et al., 1997; Mc Millan et al., 2003). Raceway could potentially address the major challenges associated with the aquaculture effluent production.

4.4. Lined pond culture system

Earthen ponds are conventionally used for fish farming with some boundaries like continuous water seepage; complications with soil-water chemistry haven't been understood with difficulties in determining the causes of physio chemical parameters related problems and organic load accretion (Weber et al., 2009). Hence, lining the ponds with High Density Polyethylene (HDPE) sheets has many advantages like reducing seepage, reducing pumping cost, complications due to soil-water interactions can be prevented and for undertaking advanced farming practices are more appropriate (Felix, 2006; Felix and Venkataramani, 2007). The initial investment will be largely compensated by the huge advantages in terms of net profit. Lining materials should be long lasting and cost effective (Felix, 2011).

5. OVERVIEW OF BIOFLOC TECHNOLOGY

Biofloc technology (BFT) is an innovative and sustainable method of fish production technique that has been recently received a lot of attention at global level. It entails the aquaculture system's growth by its dense communities, known as biofloc (Yu et al., 2023). The biofloc system was developed under the same principle that regular waste water treatment plants, in which the microbes grow from faeces of the cultured organisms being transforming it into less complex organic products that can be consumed by other organisms and return to the food chain (Avnimelech and Kochba, 2009).

In aquaculture, the "biofloc" system acts like retention trap for the nutrients in the pond, and reduces maintenance costs because it can be used as food supplement for the commercial organisms being cultured, which provides an added value by improving the food consumption rate (Azim and Little, 2008). To establish the BFT, it is necessary that the system has a cover that prevents the accumulation of solid organic matter at the bottom, adding carbon source that stimulates the growth of heterotrophic bacteria, and to keep constant aeration in the water column, which will help the combination of physical, chemical and biological factors, required for the floc formation (Emerenciano et al., 2011).

To develop the biofloc, biological polymers substances are required to keep the components together, creating a matrix that encapsulate the cells. This matrix protects the microorganisms from their predators, provides direct access to nutrients and works as substrate (De Schryver et al., 2008). Species biodiversity that inhabit the flocs depends on the microbiota found in the water body; some of them may function as biological control agents against pathogens through competitive exclusion or due to probiotic capabilities (Ray et al., 2010). However, to achieve the establishment of heterotrophic bacteria in the biofloc, it is necessary to adjust the carbon/nitrogen (C:N) relation in the water body, and is required around 15 units of carbon to assimilate one nitrogen unit, this is obtained by adding a food of low protein and one carbohydrate such as soya hull pellet powder in sufficient amount (Avnimelech, 1999; Emerenciano et al., 2012). When this rate is adequate, bacteria that grow inside of the microsystem starts to use compounds that can be toxic to the culture such as organic carbon, ammonia nitrogen, nitrates, nitrites, and phosphates as energy sources, oxidizing them so algae, fungi, and other bacteria and filtering organisms can use them (Avnimelech, 1999; Avnimelech, 2007).

The non-consumed nitrogen by the organisms in the culture can be used to produce microbe protein, instead of generating toxic compounds which also helps controlling toxic inorganic nitrogen, residual food, and the rest of the phytoplankton production will also be broken down into simpler compounds (Avnimelech, 1999). It is very important to note that this process reduces the total amount of dissolved oxygen available for the organisms, so the existence of an adequate concentration of this element in the water becomes very important (Abarzúa et al., 1995; Avnimelech, 1999; Mc Graw, 2003). Proliferation of bacterial colonies and microorganisms generates an increase in the biofloc biomass, this increase must have a density between 10 and 15 ml so the system can keep functioning properly (Avnimelech, 1999; De Schryver et al., 2008; Emerenciano et al., 2011).

Nevertheless, uses of biofloc technology for sustainable development in aquaculture are critical because of the essential role of microorganisms in the establishment and control of ecosystem facilities, especially nutrient cycling, water quality control, and disease regulation in the culture system (Timmis et al., 2017). Although, several microbial biotechnologies have been applied or are still in the developmental pipeline to increase the productivity in aquaculture by creating the ecofriendly environment to support the growth of other aquatic organisms. These organisms are key agents of pollutant removal and recycling (Bossier and Ekasari, 2017; Liu et al., 2019). BFT is one of such novel microbial biotechnologies that have been developed with an excellent ecofriendly technology not only for higher productivity but also for sustainable development (Emerenciano et al., 2017; Abakari et al., 2021) (Table I).

6. OVERVIEW OF POLYCULTURE

Polyculture is also referred as co-culture or integrated aquaculture (Bunting, 2008). Polyculture utilizes the concept that a mixed stock of selected species, with complementary or minimal competing feeding habits and different ecological requirements, can exploit the resources of the different ecological niches in system effectively, thereby resulting a maximum production for given input quantities (Pitt and Nguyen, 2004; Douglass et al., 2008).

Table 1: Recent use of biofloc technology (BFT) in fish and shrimp culture

Fish/ shrimp species cultured	Technology used	Effect on fish / Shrimp	Reference
Nile tilapia (*Oreochromis niloticus*)	Biochar – based BFT	No remarkable negative effects of biochar on growth and physiological performance.	Abakari et al., 2020
Nile tilapia (*Oreochromis niloticus*)	Jaggery – based BFT	Improved growth and survival; higher immunity to Aeromonas hydrophila greater antioxidant capacity.	Elayaraja et al., 2020
Genetically Improved Farmed Tilapia (Oreochromis niloticus)	FRP tank culture with isolated probiotic bacteria from BFT	Enhanced growth and survival; improved immunological parameters	Menaga et al., 2020
Amur minnow (*Rhynchocypris lagowski*)	BFT with differential protein	Enhanced growth; boosted immune response and digestive enzyme activity; higher expression of antioxidant-related genes.	Yu et al., 2020
Shrimp (*Litopenaeus vannamei*)	Wheat flour-based zero water exchange BFT	Affected growth performance	Kim et al., 2021
Shrimp (*Litopenaeus vannamei*)	Biofloc – based super intensive tank system	Better growth performance in outdoor conditions than in indoors	Xu et al., 2021

In addition, the density of organisms within the system may be a limiting factor because oxygen consumption increases as a function of biomass (Martinez-Cordova et al., 1997).

Many benefits have been achieved in shrimp polyculture systems when using fish as subordinate species, despite the fact that polyculture is not common and rarely researched. The benefits of polyculture include the diminution of ecological impacts and improvement in yield and water quality (Muangkeow et al., 2007; Troell et al., 2009). Polyculture can contribute to minimizing the environmental impact of farm effluents, particularly those related to nitrogenous wastes, which are further converted into toxic metabolites; the main reason for this is that some subordinate species can fed on and assimilate most of the waste generated from shrimp aquaculture. A higher efficiency of nitrogen utilization has been observed in polyculture systems compared with monoculture systems (Zhen-xiong et al., 2001), with a consequent decrease in nitrogen excess, improvement in water quality and diminution of the environmental impact resulting from effluent discharges. Yokoyama et al. (2002) asserted that in polyculture systems, the wastes from aquaculture are assimilated through the food web within pond microcosm formed by the co-cultured organisms and natural pond biota. There is also evidence that the diversity of species within a specific environment influences a variety of ecosystem processes including productivity, decomposition and nutrient cycling (Hooper et al., 2005; Balvanera et al., 2006; Douglass et al., 2008). Belton and Little (2008) affirmed that shrimp culture has severely affected the ecosystem and concluded that integrated aquaculture practices, such as polyculture, are good alternatives for reducing contamination (Table 2).

7. SPECIES INTERACTIONS

The interactions between farmed aquatic organisms in polyculture or co-culture depend mainly on the biological characteristics of the species and the stocking densities used. Major synergistic interactions are improvements in food availability and environmental

Table 2: Effect of polyculture on the environment and biology

Fish/ shrimp species cultured	Environment	Biology effect	Reference
Macrobrachium rosenbergii *Oreochromis niloticus*	Reduced phytoplankton densities and pH levels	Higher average weight, and more efficient feed conversion of shrimps (confined tilapia)	Danaher et al., 2007; Tidwell et al., 2010
Macrobrachium rosenbergii *Oreochromis niloticus*	Reduced phytoplankton biomass, improved the water quality	Controlled luminous bacteria	Tendencia et al., 2004; Tendencia, 2003; Tendencia et al., 2006
Macrobrachium rosenbergii *Oreochromis niloticus*	Improved system sustainability		Santos and Valenti, 2002
Ophicephalus striatus *Chanos chanos*		Did not affect the growth of milkfish	Cruz and Laudencia, 1980; Xu, 2013
Mugil liza *Litopenaeus vannamei*	Modified bacterial nitrification, reduced total suspended solids	Enhanced growth of mullet, but impaired shrimp's growth	Holanda et al., 2020
Indian major carps, rohu (*Labeo rohita*), catla (*Catla catla*), and mrigal (*Cirrihinus mrigala*)	Maintenance of NH_4 -N, NO_2-N and NO_3 -N in the acceptable range of water quality	Satisfactory growth performance (higher rate of specific growth)	Deb et al., 2020

conditions (Milstein, 1992). On the other hand, the major antagonistic interactions are competition for food, space, oxygen, and other resources within the growout unit and agonistic behavior. Thus, the use of ecologically different species that have complementary requirements and planning a suitable density for each are the keys for successful polyculture.

Shrimp and tilapia match the fundamentals described above mainly because of differing feeding habits and spatial distribution. Shrimp are benthic and omnivorous in production ponds, eating commercial feed, detritus, waste, and feces (D'Abramo and New, 2000). Tilapias are pelagic and omnivorous, filtering phytoplankton (Wang and Lu, 2015), eating periphyton (Getachew, 1993; Tadesse, 1999; Sakr et al., 2015), and consuming commercial feeds. In polyculture, shrimp can eat tilapia feces and unused fish feed (Santos and Valenti, 2002), while tilapia filter phytoplankton (Perschbacher and Lorio, 1993), reducing the risk of low dissolved oxygen levels at night. In addition, shrimp bioturbation at the pond bottom returns nutrients to the water column (Kimpara et al., 2011), enhancing phytoplankton production and consequently the natural feed available for the tilapia. Therefore, shrimp and tilapia exploit different niches in the pond environment, show positive synergism and low antagonistic interactions; thus, they can be cultivated together with success.

Generally, polyculture influences water quality in a positive manner and it may decrease the need to exchange water in ponds. The benefits of introducing tilapia into shrimp ponds on the physical and chemical aspects of water quality were noted by Rouse et al. (1987) and Alston (1989) in polyculture, and by Danaher et al. (2007) and Tidwell et al. (2000) in co-culture (stocking tilapia in cages within ponds). The main benefits cited are the stabilization of dissolved oxygen and pH. These are because the tilapia consumes excess algae, lowering nocturnal respiration and the excess of photosynthesis during the day, and the shrimp consume detritus, reducing respiration at the pond bottom.

Among the various shrimp species, *Penaeus vannamei* has a consolidated and expanding production chain, due to its adaptability, rapid growth, and adaptability to polyculture with fish (Hossain and Islam, 2006). Similarly, in the farmed fish species, Genetically Improved Farmed Tilapia (GIF tilapia) is emerging as an important cultivable fish after carps. GIF tilapia strain has better growth, meat quality and good market value than normal tilapia strain (Sgnaulin et al., 2000). Besides that, *P. vannamei* and GIF tilapia has differing feeding habits and spatial distribution which is highly suitable for this hybrid system.

In shrimp farming regions, tilapia is often grown in cage or hapa inside shrimp ponds, or is produced in supply channels or head ponds. In Latin American countries such as Brazil and Mexico, red tilapia hybrids are now cultured in brackish ponds traditionally used only for shrimp farming (Alceste et al., 2001). In the Philippines, more than 60% of the shrimp farms employ tilapia–shrimp polyculture (Cruz et al., 2008). Farming tilapia and shrimp together, improves shrimp health and increases profits (Yuan et al., 2010; Hern'andez-Barraza et al., 2012). Shrimp production was generally higher in polycultures than in monocultures (Li and Dong, 2002). Tilapia/shrimp polyculture is important in the control of the luminous bacterial disease caused by *Vibrio harveyi* (Cruz et al., 2008). Studies have shown that the presence of genetically improved farmed tilapia (GIFT) reduced the luminous bacteria population and increased shrimp survival (Tendencia et al., 2006). The ability of tilapia to control luminous bacteria has been extensively studied (Tendencia et al., 2004; Tendencia and Choresca, 2006). Tilapia polyculture maintained a stable plankton environment, and increased shrimp survival (Cruz et al., 2008). Stocking performance, feeding strategies and productivity in shrimp/tilapia systems have been studied (Wang et al., 1998; Hernandez-Barraza et al., 2012).

8. HISTORY AND STATUS OF PENAEUS VANNAMEI

Penaeus vannamei is native to the tropical East Pacific from the Gulf of California, Mexico to northern Peru (Holthuis, 1989). It is now the most widely cultured shrimp in the world (Liao and Chien, 2011). It is currently raised in at least 27 countries, with major production operations occurring in the US, Mexico, Central America, tropical South America, China, India, and southeast Asia. Shrimp is one of the significant high exported commodity in world fish trade. The white leg shrimp (*Penaeus vannamei*) production has increased steadily over the last decade, and in 2020, a total of 5.8 mt were reached, making it the most-produced animal species in aquaculture. In fact, the culture of *P. vannamei* generates profits of over 33 billion USD year^{-1} worldwide. Major producers are Asian and South American countries, and in 2019, imports of *Penaeus* shrimp to Europe reached 284.270 tonnes with a total value of 1.98 billion EUR. Among the various shrimp species, *Penaeus vannamei* has a consolidated and expanding production chain, due to its adaptability, rapid growth, and adaptability to polyculture with fish (Hossain and Islam, 2006).

9. HISTORY AND STATUS OF GENETICALLY IMPROVED FARMED TILAPIA (GIF TILAPIA)

The GIFT strain was developed by World Fish Centre (WFC; formerly known as International Centre for Living Aquatic Resources Management, ICLARM) through several generations of selection from the base population involving 8 different strains of Nile tilapia *Oreochromis niloticus*. GIFT program succeeded 12–17% average genetic gain per generation over five generations and cumulative increase in growth rate of 85% in *O. niloticus* (Eknath and Acosta, 1998). The Indian government recognizes GIF tilapia farming a key sector in aquaculture, particularly considering the success of other tilapia industries in tropical and subtropical regions around the world (Menaga and Fitzsimmons, 2017). Nile tilapia (*Oreochromis niloticus*) had 3.69% of share world production quantity of all species whereas 3.05% of share of world production value of all species. Capture production of tilapia and other cichlids are 7, 12,740 tonnes in 2012 and 8, 50,770 tonnes in 2018 respectively. International exports of fishery commodities by FAO ISSCAAP of Tilapia and other cichlids in world exports are 40,273 tonnes in 1998 and in 2018 was 8,11,960 tonnes with a share in total exports of 0.11% in 1998 and 1.21% in 2018. The desirable characteristics of this genetically improved strain are of high yielding, better growth, efficient converter of organic and agricultural wastes into high quality protein, resistant to diseases, very hardy, tolerant to overcrowding conditions and adaptability to polyculture with shrimp (Sgnaulin et al., 2000).

10. BIOFLOC ON WATER QUALITY

Being an aquatic animal, fish growth and health conditions are directly anchored by water quality. Elevation of ammonia nitrogen in water body of fish pond results in fish toxicity. The traditional solutions is to exchange water of the pond frequently or applicant sophisticated labor expensive technique as rotating biological contactors, trickling filters, bead filters and fluidized sand biofilters which are usually used in intensive aquaculture systems to remove toxic nitrogen from water in production units. Microbial process is the key step in waste water treatment, as the waste degradation and elimination could be managed. Activation of the ammonia assimilating bacteria by adding carbohydrates enhances the water quality in the pond (Avnimelech, 1999; Luo et al., 2014; Wang et al., 2016 and Khanjani et al., 2016). The balance between carbon and nitrogen in biofloc system lead to enhance the water quality by minimizing the level of NH_4^+, NO_2 in ponds (Wang et al., 2016). Similar positive effect on water quality parameter (ammonia, nitrite and nitrate) was noticed in biofloc system in culture of grey mullet (Haridas et al. 2021), giant river shrimp (Hosain et al., 2021), Nile tilapia (Elayaraja et al., 2020; Azim and Little, 2008), Amur carp (Ezhilarasi et al., 2019), Pacific white shrimp (Lin and Chen, 2003; Samocha et al., 2004; Kuhn et al., 2010) and Zero water exchange system (Burford et al., 2004; Wasielesky et al., 2006; Ray et al., 2010; Vinatea et al., 2010).

The pH should be ranges from 6.5 to 9 depending on the culture species. The pH fluctuated between day and night due the action of photosynthesis and respiration. Growth and survival of the culture stock as well as the efficiency of the biofloc components are affected when pH is reduced or increased from their recommended values (<6 and >8.5) respectively. Emerenciano et al. (2017) reported that pH became acidic level could affect the nitrification process in biofloc system.

Temperature is an important parameter because it affects the oxygen consumption, pH, ammonia and metabolic rate of fish. Temperature ranges from 28 and 30°C is ideal for tropical fish culture but it varies depending on the cultured species. Wilen and Balmer (1999) reported that temperature should be ranges from 18 to 25°C is favor for biofloc development and which influences the floc characteristics and also microbial metabolism.

Dissolved oxygen is a crucial parameter in biofloc systems, the oxygen demand will be higher, because of the interaction between the bacteria, algae and fish size. The recommended dissolved oxygen to be maintained is 6–8 mg l^{-1} to ensure proper functioning of the system. Luo et al. (2014) stated that increasing the C: N ratio and maintaining a high DO (6 mg l^{-1}) in the culture water enabled the assimilatory activity of heterotrophic bacteria to convert ammonium into bacterial biomass in biofloc system.

Alkalinity is the total concentration of bases in the water which includes carbonate, bicarbonate and hydroxide ions. Total alkalinity ranges from 70 to 150 mg l^{-1} which provide a well buffered environment and suitable for growth of the fish and pond primary productivity (Boyd et al., 2002). Azim and Little, (2008) reported that, total alkalinity was stable in normal culture system and oscillates in AMF system due to buffering action. Hardness is a measure of alkaline ions of Calcium, Magnesium in water with other ions like Aluminium, Zinc and Hydrogen. Acceptable range of hardness in aquaculture is 50–150 ppm.

Emerson et al. (1975) state that toxicity on aquatic organisms has been attributed by ammonia (NH_3). Emerenciano et al. (2017) reported that less than 0.1 ppm of NH_3 suitable for fish culture and toxicity level mainly depends on pH of water in biofloc system. Hargreaves (2013) documented that ammonia or nitrite higher during initial stage can be reduced by adding carbohydrate. At primary stage, carbohydrate was added to lower ammonia concentration and to stimulate the heterotrophic bacterial population. The concentration of nitrites was lower and more efficient than nitrification in biofloc system (Perez-Fuentes et al., 2016).

11. FLOC PARAMETERS

Numerous studies have demonstrated that different microorganisms have amassed in biofloc systems, which play an important role in transforming the nitrogen compounds into functional feed for other organisms (Roberto et al., 2017). The created floc feed, contains various active compounds and probiotic strains, and helps in supplying energy, nutrition, and disease resistance to the fish (Ahmad et al., 2017). According to Crab et al. (2012), the applied carbon source, to promote the floc, encourages the proliferation of particular bacteria, protozoa, and algae, which affects both microbial diversity and nutritional quality of floc. Floc characteristics are influenced by dissolved oxygen, temperature, mixing intensity and carbon source (Crab et al., 2010). The metabolic activity of cells within biofloc depends on dissolved oxygen. In higher aeration, flocs tend to be larger and denser (Wilen and Balmer, 1999). Temperature is the main source of microbial metabolism. It may influence floc characteristics. More deflocculation of activated sludge flocs occurs in low temperature leading to decline in microbial activity within flocs (Wilen et al., 2000). Krishna and Loosdrecht (1999) studied that higher water temperature leads to higher production of sludge. Crab (2010) reported that at optimal water temperature about 20–25°C, flocs are stable.

Avnimelech (2007) studied that floc volume continuously increased due to the addition of carbon source with intensive aeration and subsequently fed by culture species. The desirable range of floc volume, a quantitative characteristic of biofloc, for finfish culture was 25 to 50 ml l^{-1} (Hargreaves, 2013). Krishna and Loosdrecht (1999) mentioned that the temperature between 20–25°C is suitable to obtain stable flocs with an intermediate floc volume index of about 200 ml g^{-1}. Crab et al. (2010) observed that biofloc with a higher floc volume index are produced at lower DO-levels in the biofloc ponds. Better FVI provide, the aquatic organisms enough opportunity to filter the flocs from suspension before they sediment to the bottom of the ponds. The optimum level of floc physical and chemical characteristics and suspended solids (SS) and Floc volume index (FVI) should be 0.2 to 1.0 g l^{-1} and >200 ml g^{-1} respectively (De Schryver et al., 2008).

Mueller et al. (1967) observed that the sludge floc density measured after removal of the water was 1.09 g cm^{-3}. Smith and Coakley (1984) reported that density of solid material in the flocs, with a typical constant value of 1.40 g ml^{-1}. Li et al. (1986) reported that the activated sludge floc cell density was around 1.01 g cm^{-3}. The porosity was increased in smaller flocs (<200 μm) than that of the larger flocs. Li et al. (1986) stated that the porosity of the activated sludge ranged from 82.5 to 95%. Chu and Lee (2004) reported that flocs are usually irregular in shape, size and have broad distribution with highly porous condition and observed around 99% of porosity has been observed.

Hargreaves (2013) documented that BFT system should operate with less than 500 mg l^{-1} of suspended solids. The range between 200 to 500 mg l^{-1} is appropriate for good system and this level can control ammonia without excessive water respiration. TSS between 100 to 300 mg l^{-1} ideal for the best feed consumption in shrimp raceway BFT systems. In BFT system, TSS level was gradually increased throughout the experiment based on the addition of suitable carbon source (Long et al., 2015). Ray et al. (2010) studied that over accumulation of TSS concentration in the biofloc system causes gill clogging. Van Wyk (2006) observed that limited water exchange, higher organic matter input, and improved growth rates of heterotrophic bacteria contribute to an increase of TSS level in BFT systems.

12. GROWTH PERFORMANCE

Combining of biofloc with polyculture offers several advantages such as better growth characteristics (Hisano et al., 2019), minimizes the feed and water input, and effluent production (Reinoso et al., 2019; Martins et al., 2020). Barbosa et al. (2022) studied on the polyculture of fresh water shrimp with Nile tilapia using an aquaponic system and biofloc technology and stated that no significant difference were observed with respect to zootechnical performance. Polyculture of tilapia and river shrimp in a system of biofloc expressed a higher growth, which was reflected in a greater productivity, meeting the challenge of producing more in a smaller volume of water (Reinoso et al., 2019). Hisano et al. (2019) stated that polyculture of Nile tilapia and freshwater shrimp in BFT provides better growth performance comparing to RAS. Poli et al. (2019) demonstrated that feasibility of increasing yield by integrating *L. vannamei* and *O. niloticus* in a biofloc system. Polyculture of Nile tilapia (*O. niloticus*) and marine shrimp (*L. vannamei*) displayed better economical and performance indicator in comparison with monoculture (Bessa Junior et al., 2012).

Polyculture technology in biofloc system improved the growth performance of mullet and *P. vannamei* with better utilization of residues and microbial aggregates as food source which met the nutritional requirements up to 50% (da Rocha et al., 2012). Similarly, Hoang et al. (2020) studied on polyculture of mullet (*M. cephalus*), tilapia (*O. niloticus*) with white shrimp (*P. vannamei*) and stated that shrimp-fish polyculture with a stocking density of fish at 10% of the initial shrimp biomass resulted in better growth of mullet, tilapia and white shrimp. Integration of shrimp and mullet in biofloc increases yield without compromising fish health and shrimp growth (Legarda et al., 2019). Jatoba et al. (2011) studied on the polyculture of Nile tilapia (*O. niloticus*) with marine shrimp (*L. vannamei*) fed with *Lactobacillus plantarum* resulted in increased final weight and feed efficiency. Co-culture of shrimp and tilapia resulted in better yield and physiological responses (Apun-Molina et al., 2015). Polyculture of Nile tilapia and shrimp at suitable stocking densities and appropriate feeding rates results in positive interactions and better growth performance in recirculating system (Hernández-Barraza et al., 2013). Polyculture is more efficient with the combination of 2 tilapia and 5 shrimp m^{-2} (Simão et al., 2013). Hosseini Aghuzbeni et al. (2017) studied on the polyculture of white shrimp with mullet and stated that polyculture improves growth and production of white shrimp. Integrated system with a low tilapia-shrimp ratio (the ratio of 0.01 and 0.025) were effective to improve the growth and nutrient conversion ratio without lowering shrimp growth (Muangkeow et al., 2007).

13. DIGESTIVE ENZYME ACTIVITY

Biofloc plays an important role in stimulating the activities of digestive enzymes (Moss et al., 2001) by promoting the breakdown of nutrients into simple molecules which further converted into building blocks (Dong et al., 2018). In general, ability of an organism to digest, absorb and utilize the nutrients was directly indicated by the digestive enzyme activity. Knowledge of digestive enzymes in an organism helps to determine its digestive capabilities, which in turn helps the selection of ingredients to be included in a diet.

Xu and Pan (2012) reported the enhancement of protease and amylase activities of the *L. vannamei* grown in the biofloc based system and suggested that appropriate extracellular enzyme activities are present in biofloc. Few beneficial bacteria such as *Bacillus* sp. in the ingested biofloc could facilitate the modification of physiological and immunological status of the host, through the colonization in the gastrointestinal tract (Zhao et al., 2012; Xu and Pan, 2013). Xu et al. (2013) suggested that the microbial flocs could exert a positive effect on the digestive enzyme activity of *L. vannamei* which can facilitate feed digestion and utilization. In biofloc system different microorganisms can produce different kind of enzyme to breakdown the protein, lipid and other particles, when these particles ingested in shrimp it will also improve the digestion of the animal. Anand et al. (2013) reported that the dietary inclusion of biofloc enhance the digestive enzyme activity with high growth rate in *Penaeus monodon*.

Wang et al. (2015) reported that protease enzyme activity was higher in the biofloc cultured crucian carp compared to the clear water system. Long et al. (2015) reported that BFT treatment had a stimulatory effect on the digestive enzyme activity. Biofloc are rich source of heterogenous microbial cells, bioactive compounds and thus exogenous enzymes of biofloc have enhanced the digestive enzyme activities of *L. rohita* (Ahmad et al., 2019, Ahmad et al., 2016; Mahanand et al., 2013). Najdegerami et al. (2016) stated that common carp fingerlings can adapt well to nutritional conditions and that microbial flocs stimulated the production and/or activity of digestive enzymes, resulting in improved digestion of nutrients in the gut.

14. HEMATOLOGY

The most convenient tool for the fish culturist to assess clinical status is hematology. Hematological parameters such as hematocrit, hemoglobin, number of erythrocytes and white blood cells are indicators of fish health with respect to nutrition and feeding. Hematological parameters act as physiological indicators to changing external environment as a result of their relationship with energetic (metabolic levels), respiration (Hb levels) and defense mechanisms (leucocytes level) and provide an integrated measure of the health status of an organism which manifest in changes in growth (Ishikawa et al., 2007). Normal ranges for various blood parameters in fish have been established by different investigators in fish physiology and pathology (Rambhaskar and Srinivasa Rao, 1987; Zhou et al., 2009). The analysis of blood indices has proven to be a valuable approach for analyzing the health status of farmed animals as these indices provide reliable information on metabolic disorders, deficiencies and chronic stress status before they are present in a clinical setting (Bahmani et al., 2001).

Bakhshi et al. (2018) studied on common carp reared in biofloc and reported that increase in RBCs count in comparison with control (without carbon source). No significant effect was observed on hematology parameters of tilapia, *O. niloticus* reared in biofloc (Long et al., 2015; Azim and Little, 2008; Mabroke, 2018; El-Husseiny et al., 2018). Tilapia, *O. niloticus* reared at low density in biofloc has shown significant difference in WBC in comparison with clear water (Hwihy et al., 2021). Significantly decreased hematological indices (RBC, WBC, HGB and blood platelets) were reported by increasing stocking density of Nile tilapia reared in biofloc treatment (Mehrim, 2009; Kpundeh et al., 2013 and Zaki et al., 2020). Mansour et al. (2017) studied on Nile tilapia, *O. niloticus* reared in biofloc with dietary plant protein levels and stated that fish reared under BFT showed higher WBC counts than fish maintained in clear water. Mansour and Esteban, (2017), has reported that *O. niloticus* reared in biofloc culture has increased hemoglobin and hematocrit value.

15. BLOOD BIOCHEMISTRY

Blood biochemistry parameters can be also used to detect the health of fish (De Pedro et al., 2005). Exogenous factors, such as management (Svobodova et al., 2008), diseases (Chen et al., 2005) and stress (Cnaani et al., 2004), always induce major changes in blood composition. For example, significant fluctuations were detected in the concentrations of glucose, cholesterol and other basic components in response to handling and hypoxic stress (Skjervold et al., 2001). Cholesterol is mainly synthesized in liver and is an intermediate product in lipid, carbohydrate, and protein metabolism. The levels of glucose are considered to be specific indicators of sympathetic activation during stress conditions (Lermen et al., 2004). Basic ecological factors, such as feeding regime and stocking density, also have a direct influence on certain biochemistry parameters (Coz-Rakovac et al., 2005).

Studies on mullet, *M. cephalus* reared in biofloc has increased total protein and globulin levels when integrated with *L. vannamei* (Legarda et al., 2019). Similarly, increased total plasma and globulin were reported in mullet, *M. cephalus* reared in biofloc treatment (Kakoolaki et al., 2016; Akbary et al., 2018). No significant effect was observed on total protein of tilapia, *O. niloticus* reared in biofloc and control group (Long et al., 2015). The biochemical parameters of the blood serum were significantly improved in biofloc treatment in comparison with other treatments in *O. niloticus* (Azim and Little, 2008; Martins et al., 2017; Sayed and Moneeb, 2015).

16. IMMUNE PARAMETERS

Hemolymph parameters are mostly used to monitor the physiological condition, nutritional quality and status of immune systems in crustaceans exposed to various stressors (Matozzo et al., 2011; Porchas Cornejo et al., 2011). The circulating haemocyte count of crustaceans in terms of both increase in quantity and quality and ProPO activity indicated enhanced immune status in crustaceans and hence disease resistance (Rodriguwz and Le Moullac, 2000; Chiu et al., 2007). Increased haemocyte count was reported in *L. vannamei* (Xu and Pan, 2013; Panigrahi et al., 2017, 2018 and 2019; Abbaszadeh et al., 2019; Tong et al., 2020), *P. monodon* (Kumar et al., 2017) and *P. indicus* (Panigrahi et al., 2020) in biofloc based systems. Shrimps evidently consume microbial floc in situ in biofloc systems (Crab et al., 2012), that increases THC and ProPO activity in *P. vannamei* biofloc systems (Kim et al., 2014). Similarly, higher PO activity was observed in *L. vannamei* (Ekasari et al., 2014), *P. monodon* (Kumar et al., 2017) and *P. indicus* (Panigrahi et al., 2020) when grown in biofloc systems than in clear water system. This improvement might be attributed to the consumption of large quantity of bacteria (*Bacillus* and *Lactobacillus*) associated with biofloc by the shrimp that has probably released immune-stimulatory substances in the intestinal tract and could significantly enhanced the immune status in *P. vannamei* juveniles in biofloc system.

17. BACTERIAL COMMUNITY IN BIOFLOC SYSTEM

17.1. Culture water

Avnimelech (1999) studied that addition of carbon source increase the total heterotrophic bacterial count in biofloc system. De Schryver et al. (2008) stated that different carbon sources were used for biofloc production and revealed that carbon source determines the composition of the floc. This could have an effect on the bacterial populations that are closely associated with the flocs.

Caipang et al. (2015) reported that the total heterotrophic bacterial populations were significantly higher in the biofloc groups than the control due to the addition of sweet potato as carbon source and earlier study was carried out by using wheat and corn flour as carbon sources for biofloc production in freshwater tilapia culture. Manan et al. (2017) studied that *Aeromonas* and *Pseudomonas* species were identified as heterotrophic bacteria from their experiment and organic compounds were used as the source of energy by heterotrophic bacteria derived from the organic matter.

Vibrio load was decreased in biofloc system through higher diversity of phytoplankton and algae and also can also compete with dominant number of heterotrophic bacteria (Manan et al., 2017). Emerenciano et al. (2013) discovered that the natural probiotic in the biofloc could fight against the *Vibrio* sp.

Kumar et al. (2017) observed highest mean total bacterial count in *P. monodon* reared in biofloc generated from molasses with *Bacillus* being the most dominant bacterial group followed by *Vibrio* and *Lactobacillus*. Similarly, Panigrahi et al. (2019) also reported that carbohydrate supplementation systems significantly increasing the total heterotrophic bacteria (THB) count in biofloc system when compared with control group in *P. vannamei*. Recently, Khoa et al. (2020) found significantly high THB and *Vibrio* loads in biofloc treatment tanks reared *L. vannamei* when compared with control. Furthermore, Sundaram et al. (2021) recorded significantly high THB loads in substrate integrated biofloc systems than clear water control system in *P. vannamei*.

17.2. *Gut flora*

Del'Duca (2015) reported that the bacterial community composition of gastrointestinal tract in tilapia was resembled the composition in water than the sediment in the pond. Total bacterial abundance of the intestinal tract of juvenile tilapia was significantly higher than that of water. In gastrointestinal tract of juvenile tilapia and water, the abundances of *Lactobacillus brevis*, *Lactobacillus collinoides* and *Pseudomonas fluorescens* were significantly higher than other bacterial groups and proportional value of Bacillus was significantly higher in fish than in water (Del'Duca, 2015). Chethurajupalli and Tambireddy (2021) found significantly higher THB, *Bacillus, Lactobacillus* and *Vibrio* count in biofloc treatment reared *L. vannamei* compared to control.

18. CONCLUSION

Polyculture study suggests this hybrid system as sustainable, profitable and environmentally beneficial technology.

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22. REFERENCES

Abakari, G., Luo, G., Kombat, E.O., 2021. Dynamics of nitrogenous compounds and their control in biofloc technology (BFT) systems: A review. Aquaculture and Fisheries 6(5), 441–447.

Abakari, G., Luo, G., Meng, H., Yang, Z., Owusu-Afriyie, G., Kombat, E.O., Alhassan, E.H., 2020. The use of biochar in the production of tilapia (*Oreochromis niloticus*) in a biofloc technology system-BFT. Aquacultural Engineering 91, 102123.

Abarzúa, M., Basualto, S., Urrutia, H., 1995. Relationship between the abundance and biomass of phytoplankton and heterotrophic bacterioplankton in surface waters of the Gulf of Arauco, Chile. Marine Research 23, 67–74.

Abbaszadeh, A., Yavari, V., Hoseini, S.J., Nafisi, M., Torfi Mozanzadeh, M., 2019. Effects of different carbon sources and dietary protein levels in a biofloc system on growth performance, immune response against white spot syndrome virus infection and cathepsin L gene expression of *Litopenaeus vannamei*. Aquaculture Research 50(4), 1162–1176.

Ahmad, I., Babitha Rani, A.M., Verma, A.K., Maqsood, M., 2017. Biofloc technology: an emerging avenue in aquatic animal healthcare and nutrition. Aquaculture International 25, 1215–1226.

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. Aquaculture Research 50(10), 2879–2887.

Ahmad, I., Verma, A., Rani, A. B., Rathore, G., Saharan, N., & Gora, A. H. 2016. Growth, non-specific immunity and disease resistance of *Labeo rohita* against *Aeromonas hydrophila* in biofloc systems using different carbon sources. Aquaculture 457, 61–67.

Akbary, P., Sartipi Yarahmadi, S., Jahanbakhshi, A., 2018.

Hematological, hepatic enzymes' activity and oxidative stress responses of gray mullet (*Mugil cephalus*) after sub-acute exposure to copper oxide. Environmental Science and Pollution Research 25, 1800–1808.

Alceste, C.C., Illingworth, J.A., Jory, D.E., 2001. Tilapia farming industry in Ecuador. Aquaculture Magazine 27, 77–82.

Alston, D.E., 1989. Macrobrachium culture: a Caribbean perspective. World Aquaculture 20(1), 19–23.

Anand, P.S., Kohli, M.P.S., Roy, S.D., Sundaray, J.K., Kumar, S., Sinha, A., Pailan, G.H., kumar Sukham, M., 2013. Effect of dietary supplementation of periphyton on growth performance and digestive enzyme activities in *Penaeus monodon*. Aquaculture 392, 59–68.

Apún-Molina, J.P., Santamaría-Miranda, A., Luna-González, A., Ibarra-Gámez, J.C., Medina-Alcantar, V., Racotta, I., 2015. Growth and metabolic responses of white leg shrimp *Litopenaeus vannamei* and Nile tilapia *Oreochromis niloticus* in polyculture fed with potential probiotic microorganisms on different schedules. Latin American Journal of Aquatic Research 43(3), 435–445.

Attasat, S., Wanichpongpan, P., Ruenglertpanyakul, W., 2013. Design of integrated aquaculture of the Pacific white shrimp, tilapia and green seaweed. Journal of Sustainable Energy and Environment 4, 9–14.

Avnimelech, Y., 1999. Biofloc technology: a practical guide book. World Aquaculture Society. Baton Rouge, United States.

Avnimelech, Y., 1999. Carbon/nitrogen ratio as a control element in aquaculture systems. Aquaculture 176(3–4), 227–235.

Avnimelech, Y., 2006. Bio-filters: the need for an new comprehensive approach. Aquacultural Engineering 34(3), 172–178.

Avnimelech, Y., 2007. Feeding with microbial flocs by tilapia in minimal discharge bio-flocs technology ponds. Aquaculture 264(1–4), 140–147.

Avnimelech, Y., Kochba, M., 2009. Evaluation of nitrogen uptake and excretion by tilapia in bio floc tanks, using 15N tracing. Aquaculture 287(1–2), 163–168.

Avnimelech, Y., Kochva, M., Diab, S., 1994. Development of controlled intensive aquaculture systems with a limited water exchange and adjusted carbon to nitrogen ratio. Israeli Journal of Aquaculture-Bamidgeh 46(3), 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(1–4), 29–35.

Azim, M.E., Rahaman, M.M., Wahab, M.A., Asaeda, T., Little, D.C., Verdegem, M.C.J., 2004. Periphyton-based pond polyculture system: a bioeconomic comparison of on-farm and on-station trials. Aquaculture 242 (1–4), 381–396.

Bahmani, M., Kazemi, R., Donskaya, P.J.F.P., 2001. A comparative study of some hematological features in young reared sturgeons (*Acipenser persicus* and *Huso huso*). Fish Physiology and Biochemistry 24, 135–140.

Bakhshi, F., H 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. Aquaculture Research 49(1), 393–403.

Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J.S., Nakashizuka, T., Raffaelli, D., Schmid, B., 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters 9(10), 1146–1156.

Barbosa, P.T.L., Povh, J.A., Farias, K.N.N., da Silva, T.V., Teodoro, G.C., Ribeiro, J.S., Stringhetta, G.R., dos Santos Fernandes, C.E., Corrêa Filho, R.A.C., 2022. Nile tilapia production in polyculture with freshwater shrimp using an aquaponic system and biofloc technology. Aquaculture 551, 737916.

Bauer, W., Prentice-Hernandez, C., Tesser, M.B., Wasielesky Jr, W., Poersch, L.H., 2012. Substitution of fishmeal with microbial floc meal and soy protein concentrate in diets for the pacific white shrimp *Litopenaeus vannamei*. Aquaculture 342, 112–116.

Belton, B., Little, D., 2008. The development of aquaculture in central Thailand: domestic demand versus export-led production. Journal of Agrarian Change 8(1), 123–143.

Bessa Junior, A.P., Azevedo, C.M.D.S.B., Henry-Silva, G.G., 2012. Polyculture of Nile tilapia and shrimp at different stocking densities. Revista Brasileira de Zootecnia 41, 1561–1569.

Bossier, P., Ekasari, J., 2017. Biofloc technology application in aquaculture to support sustainable development goals. Microbial Biotechnology 10(5), 1012–1016.

Boyd, C.E., Thunjai, T., Boonyaratpalin, M., 2002. Dissolved salts in water for inland low-salinity shrimp culture. Global Aquaculture Advocate 5(3), 40–45.

Bunting, S.W., 2008. Horizontally integrated aquaculture development: exploring consensus on constraints and opportunities with a stakeholder Delphi. Aquaculture International 16, 153–169.

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 (1–4), 525–537.
Caipang, C.M.A., Choo, H.X., Bai, Z., Huang, H., Lay-yag, C.M., 2015. Viability of sweet potato flour as carbon source for the production of biofloc in freshwater culture of tilapia, *Oreochromis* sp. International Aquatic Research 7, 329–336.
Chen, Y.E., Jin, S., Wang, G.L., 2005. Study on blood physiological and biochemical indices of *Vibrio alginilyticus* disease of *Lateolabrax japonicas*. Journal of Oceanography in Taiwan Strait 24(1), 104–108.
Chethurajupalli, L., Tambireddy, N., 2021. Rearing of white leg shrimp *Litopenaeus vannamei* (Boone, 1931) in biofloc and substrate systems: microbial community of water, growth and immune response of shrimp. Turkish Journal of Fisheries and Aquatic Sciences 22(3).
Chiu, C.H., Guu, Y.K., Liu, C.H., Pan, T.M., Cheng, W., 2007. Immune responses and gene expression in white shrimp, *Litopenaeus vannamei*, induced by *Lactobacillus plantarum*. Fish and Shellfish Immunology 23(2), 364–377.
Chu, C.P., Lee, D.J., 2004. Multiscale structures of biological flocs. Chemical Engineering Science 59(8–9), 1875–1883.
Cnaani, A., Tinman, S., Avidar, Y., Ron, M., Hulata, G., 2004. Comparative study of biochemical parameters in response to stress in *Oreochromis aureus*, *O. mossambicus* and two strains of *O. niloticus*. Aquaculture Research 35(15), 1434–1440.
Costa Pierce, Barry A. 2005. Urban Aquaculture. Technology and Engineering, 285.
Coz-Rakovac, R., Strunjak-Perovic1, I., Hacmanjek, M., Popovic, N.T., Lipej, Z., Sostaric, B., 2005. Blood chemistry and histological properties of wild and cultured sea bass (*Dicentrarchus labrax*) in the North Adriatic Sea. Veterinary Research Communications 29, 677–687.
Crab R, Avnimelech Y, Defoirdt T, Bossier P, Verstraete W., 2007. Nitrogen removal techniques in aquaculture for a sustainable production. Aquaculture 270, 1–14.
Crab, R., 2010. Bioflocs technology: an integrated system for the removal of nutrients and simultaneous production of feed in aquaculture (Doctoral dissertation, Ghent University).
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. Aquaculture Research 41(4), 559–567.
Crab, R., Defoirdt, T., Bossier, P., Verstraete, W., 2012. Biofloc technology in aquaculture: beneficial effects and future challenges. Aquaculture 356, 351–356.
Cruz, E.M., Laudencia, I.L., 1980. Polyculture of milkfish (*Chanos chanos* Forskal), all-male Nile tilapia (*Tilapia nilotica*) and snakehead (*Ophicephalus striatus*) in freshwater ponds with supplemental feeding. Aquaculture 20(3), 231–237.
Cruz, P.S., Andalecio, M.N., Bolivar, R.B., Fitzsimmons, K., 2008. Tilapia–shrimp polyculture in Negros Island, Philippines: a review. Journal of the World Aquaculture Society 39(6), 713–725.
da Rocha, A.F., Abreu, P.C., Junior, W.W., Tesser, M.B., 2012. Avaliação da formação de bioflocos na criação de juvenis de tainha mugil cf. hospes sem renovação de água. Atlântica (Rio Grande) 34(1), 63–74.
D'Abramo, L.R., New, M.B., 2000. Nutrition, feeds and feeding. Freshwater prawn culture: The Farming of Macrobrachium Rosenbergii, 203–220.
Danaher, J.J., Tidwell, J.H., Coyle, S.D., Dasgupta, S., Zimba, P.V., 2007. Effects of two densities of caged monosex nile tilapia, *Oreochromis niloticus*, on water quality, phytoplankton populations, and production when polycultured with *Macrobrachium rosenbergii* in temperate ponds. Journal of the World Aquaculture Society 38(3), 367–382.
Datta, S., 2011. Inland Fisheries Resources of India. CIFE, Kolkata Centre, Article in Inland Water Biology.
De Pedro, N., Guijarro, A.I., López-Patiño, M.A., Martínez-Álvarez, R., Delgado, M.J., 2005. Daily and seasonal variations in haematological and blood biochemical parameters in the tench, *Tinca tinca* Linnaeus, 1758. Aquaculture Research 36(12), 1185–1196.
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(3–4), 125–137.
Deb, S., Noori, M.T., Rao, P.S., 2020. Application of biofloc technology for Indian major carp culture (polyculture) along with water quality management. Aquacultural Engineering 91, 102106.
Del'Duca, A., Cesar, D.E., Abreu, P.C., 2015. Bacterial community of pond's water, sediment and in the guts of tilapia (*Oreochromis niloticus*) juveniles characterized by fluorescent in situ hybridization technique. Aquaculture Research 46(3), 707–715.
Dong, J., Zhao, Y.Y., Yu, Y.H., Sun, N., Li, Y.D., Wei, H., Yang, Z.Q., Li, X.D., Li, L., 2018. Effect of stocking density on growth performance, digestive enzyme activities, and non-specific immune parameters of *Palaemonetes sinensis*. Fish & Shellfish Immunology 73, 37–41.
Douglass, J.G., Duffy, J.E., Bruno, J.F., 2008. Herbivore and predator diversity interactively affect ecosystem

properties in an experimental marine community. Ecology Letters 11(6), 598–608.

Ekasari, J., Azhar, M.H., 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 and Shellfish Immunology 41(2), 332–339.

Eknath, A.E., Acosta, B.O., 1998. Genetic improvement of farmed tilapias (GIFT) project: Final report, March 1988 to December 1997.

Elayaraja, S., Mabrok, M., Algammal, A., Sabitha, E., Rajeswari, M.V., Zágoršek, K., Ye, Z., Zhu, S., Rodkhum, C., 2020. Potential influence of jaggery-based biofloc technology at different C: N ratios on water quality, growth performance, innate immunity, immune-related genes expression profiles, and disease resistance against Aeromonas hydrophila in Nile tilapia (*Oreochromis niloticus*). Fish & Shellfish Immunology 107, 118–128.

El-Husseiny, O.M., Goda, A.M.A.S., Mabroke, R.S., Soaudy, M., 2018. Complexity of carbon sources and the impact on biofloc integrity and quality in tilapia (*Oreochromis niloticus*) Tanks. AACL Bioflux 11(3), 846–855.

Emerenciano, M., Ballester, E., Cavalli, R., Wasielesky, W., 2011. Biofloc technology application as a food resource in a limited water exchange nursery system for pink shrimp *Farfantepenaeus brasiliensis* (Latreille, 1817). Aquaculture Research, 1–11.

Emerenciano, M., Ballester, E.L., 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). Aquaculture Research 43(3), 447–457.

Emerenciano, M., Gaxiola, G., Cuzon, G., 2013. Biofloc technology (BFT): a review for aquaculture application and animal food industry. Biomass Now-Cultivation and Utilization 12, 301–328.

Emerenciano, M.G.C., Martínez-Córdova, L.R., Martínez-Porchas, M., Miranda-Baeza, A., 2017. Biofloc technology (BFT): a tool for water quality management in aquaculture. Water Quality 5, 92–109.

Emerson, K., Russo, R.C., Lund, R.E., Thurston, R.V., 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. Journal of the Fisheries Board of Canada 32(12), 2379–2383.

Ezhilarasi, V., Verma, A.K., Rani, A.B., Harikrishna, V., Chandrakant, M.H., Ahmad, I., Nageswari, P., 2019. Effect of different carbon sources on growth, non-specific immunity and digestive enzyme activity of amur carp (*Cyprinus rubrofuscus* Lacepede 1803) fingerlings in biofloc based rearing system using inland saline groundwater. Indian Journal of Fisheries 66(3), 87–94.

Felix, S., 2006. Shrimp raceway technology. DBT, New Delhi and TANUVAS, Chennai 9–1.

Felix, S., 2011. Innovative culture systems to enhance inland fish production in India.

Felix, S., 2012. Biosecured Aerobic Flocculent driven raceway farming technology for mass production of ornamental fishes in India. Proceedings of the international conference on sustainable ornamental fisheries – way forward. Cochin University of science and technology, Kochi, 23 to 25 March, 2012. 200.

Felix, S., Venkataramani, V.K., 2007. Enhancing penaid shrimp (*Fenneropenaeus indicus*) yield through biosecured nursery raceway technology. In: Felix, S., Venkataramani, V.K. (Eds), proceeding of the conference on biosecured aquaculture-an eco-friendly approach (BAAE'07), held during 28–29, June 2007 at FCRI, Thoothukudi, india.

Getachew, T., 1993. The composition and nutritional status of the diet of *Oreochromis niloticus* in Lake Chamo, Ethiopia. Journal of Fish Biology 42(6), 865–874.

Handbook, F.S., 2019. Handbook on Fisheries Statistics 2018. Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi, 1–190.

Hargreaves, J.A., 2013. Biofloc production systems for aquaculture. SRAC, 4503, 1–12.

Haridas, H., Chadha, N.K., Sawant, P.B., Deo, A.D., Ande, M.P., Syamala, K., Sontakke, R., Lingam, S.S., 2021. Different carbon sources influence the growth and digestive enzyme activity of grey mullet (*Mugil cephalus*) in biofloc based nursery rearing system. Journal of Environmental Biology 42(5), 1249–1256.

Hernández-Barraza, C., Cantú, D.L., Osti, J.L., Fitzsimmons, K., Nelson, S., 2013. Productivity of polycultured Nile tilapia (*Oreochromis niloticus*) and Pacific white shrimp (*Litopenaeus vannamei*) in a recirculating system. Israeli Journal of Aquaculture 65(5).

Hernández-Barraza, C., Loredo, J., Adame, J., Fitzsimmons, K.M., 2012. Effect of Nile tilapia (*Oreochromis niloticus*) on the growth performance of Pacific white shrimp (*Litopenaeus vannamei*) in a sequential polyculture system. Latin American Journal of Aquatic Research 40(4), 936–942.

Hisano, H., Barbosa, P.T., Hayd, L.A., Mattioli, C.C., 2019. Evaluation of Nile tilapia in monoculture and polyculture with giant freshwater prawn in biofloc technology system and in recirculation aquaculture system. International Aquatic Research 11(4), 335–346.

Hoang, M.N., Nguyen, P.N., Maria Vital Estrocio Martins Bossier, A., Bossier, P., 2020. The effects of two fish species mullet, Mugil cephalus, and tilapia, *Oreochromis niloticus*, in polyculture with white shrimp, *Litopenaeus vannamei*, on system performances: A comparative study. Aquaculture Research 51(6), 2603–2612.

Holanda, M., Santana, G., Furtado, P., Rodrigues, R.V., Cerqueira, V.R., Sampaio, L.A., Wasielesky Jr, W., Poersch, L.H., 2020. Evidence of total suspended solids control by *Mugil liza* reared in an integrated system with pacific white shrimp Litopenaeus vannamei using biofloc technology. Aquaculture Reports 18, 100479.

Holthuis, L.B., 1980. Shrimps and prawns of the world. An annotated catalogue of the species of interest to fisheries, 1.

Hooper, D.U., Chapin III, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75(1), 3–35.

Hosain, M.E., Amin, S.N., Arshad, A., Kamarudin, M.S., Karim, M., 2021. Effects of carbon sources on the culture of giant river prawn in biofloc system during nursery phase. Aquaculture Reports 19, 100607.

Hossain, M.A., Islam, M.S., 2006. Optimization of stocking density of freshwater prawn *Macrobrachium rosenbergii* (de Man) in carp polyculture in Bangladesh. Aquaculture Research 37(10), 994–1000.

Hosseini Aghuzbeni, S.H., Hajirezaee, S., Matinfar, A., Khara, H., Ghobadi, M., 2017. A preliminary study on polyculture of western white shrimp (*Litopenaeus vannamei*) with mullet (*Mugil cephalus*): an assessment of water quality, growth parameters, feed intake efficiency and survival. Journal of Applied Animal Research 45(1), 247–251.

Hwihy, H., Zeina, A., Abu Husien, M., El-Damhougy, K., 2021. Impact of Biofloc technology on growth performance and biochemical parameters of *Oreochromis niloticus*. Egyptian Journal of Aquatic Biology and Fisheries 25(1), 761–774.

Ishikawa, N.M., Ranzani-Paiva, M.J.T., Lombardi, J.V., Ferreira, C.M., 2007. Hematological parameters in Nile Tilápia, *Oreochromis niloticus* exposed to sub-letal concentrations of mercury. Brazilian Archives of Biology and Technology 50, 619–626.

Jatobá, A., Vieira, F.D.N., Buglione-Neto, C.C., Mouriño', J.L.P., Silva, B.C., Seiftter, W.Q., Andreatta, E.R., 2011. Diet supplemented with probiotic for Nile tilapia in polyculture system with marine shrimp. Fish Physiology and Biochemistry 37, 725–732.

Jayasankar, P., 2018. Present status of freshwater aquaculture in India-A review. Indian Journal of Fisheries 65(4), 157–165.

Jhingran, V.G., 1975. Aquaplosion Lecture, Summer Int. Intensive Freshwater Fish Culture, Cuttack, Organized by centre, Inland Fish Res. Inst., Barrackpore (ICAR), 12.

Kakaei, H., Nourmoradi, H., Bakhtiyari, S., Jalilian, M., Mirzaei, A., 2022. Effect of COVID-19 on food security, hunger, and food crisis. In COVID-19 and the sustainable development goals (3-29). Elsevier.

Kakoolaki, S., Akbary, P., Zorriehzahra, M.J., Salehi, H., Sepahdari, A., Afsharnasab, M., Mehrabi, M.R., Jadgal, S., 2016. *Camellia sinensis* supplemented diet enhances the innate non-specific responses, haematological parameters and growth performance in *Mugil cephalus* against *Photobacterium damselae*. Fish & Shellfish Immunology 57, 379–385.

Khanjani. M.H., Sajjad, M.M., Alizadeh, M., Sourinejad, M., 2016. Nursery performance of Pacific white shrimp (*Litopenaeus vannamei* Boone, 1931) cultivated in a biofloc system: the effect of adding different carbon sources. Aquaculture Research, 1–11.

Khoa, T.N.D., Tao, C.T., Van Khanh, L., Hai, T.N., 2020. Super-intensive culture of white leg shrimp (*Litopenaeus vannamei*) in outdoor biofloc systems with different sunlight exposure levels: Emphasis on commercial applications. Aquaculture 524, 735277.

Kim, S.K., Pang, Z., Seo, H.C., Cho, Y.R., Samocha, T., Jang, I.K., 2014. Effect of bioflocs on growth and immune activity of Pacific white shrimp, *Litopenaeus vannamei* postlarvae. Aquaculture Research 45(2), 362–371.

Kim, Y.S., Kim, S.E., Kim, S.J., Jung, H.K., Park, J., Jeon, Y.J., Kim, D.H., Kang, J.H., Kim, K.H., 2021. Effects of wheat flour and culture period on bacterial community composition in digestive tracts of *Litopenaeus vannamei* and rearing water in biofloc aquaculture system. Aquaculture 531, 735908.

Kimpara, J.M., Tito Rosa, F.R., de Lima Preto, B., Valenti, W.C., 2011. Limnology of *Macrobrachium amazonicum* grow-out ponds subject to high inflow of nutrient-rich water and different stocking and harvest management. Aquaculture Research 42(9), 1289–1297.

Kpundeh, M.D., Xu Pao, X.P., Yang Hong, Y.H., Qiang Jun, Q.J., He Jie, H.J., 2013. Stocking densities and chronic zero culture water exchange stress' effects on biological performances, hematological and serum biochemical indices of gift tilapia juveniles (*Oreochromis niloticus*). Journal of Aquaculture Research and Development 4(189), 2.

Krishna, C., Van Loosdrecht, M.C., 1999. Effect of temperature on storage polymers and settleability of activated sludge. Water Research 33(10), 2374–2382.

Kuhn, D.D., Lawrence, A.L., Boardman, G.D., Patnaik, S., Marsh, L., Flick Jr, 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(1–4), 28–33.

Kumar, S., Anand, P.S.S., De, D., Deo, A.D., Ghoshal, T.K., Sundaray, J.K., Ponniah, A.G., Jithendran, K.P., Raja, R.A., Biswas, G., Lalitha, N., 2017. Effects of biofloc under different carbon sources and protein levels on water quality, growth performance and immune responses in black tiger shrimp *Penaeus monodon* (Fabricius, 1978). Aquaculture Research 48(3), 1168–1182.

Lawrence, A.L., Castille, F., Velasco, M., Samocha, T., 2001. Environmentally friendly" or" least polluting" feed management program for shrimp farming. Aquaculture 2001: Book of Abstracts 352, 2001.

Legarda, E.C., Poli, M.A., Martins, M.A., Pereira, S.A., Martins, M.L., Machado, C., de Lorenzo, M.A., do Nascimento Vieira, F., 2019. Integrated recirculating aquaculture system for mullet and shrimp using biofloc technology. Aquaculture 512, 734308.

Lermen, C.L., Lappe, R., Crestani, M., Vieira, V.P., Gioda, C.R., Schetinger, M.R.C., Baldisserotto, B., Moraes, G., Morsch, V.M., 2004. Effect of different temperature regimes on metabolic and blood parameters of silver catfish *Rhamdia quelen*. Aquaculture 239 (1–4), 497–507.

Li, D., Dong, S., 2002. Summary of studies on closed-polyculture of penaeid shrimp with tilapia and molluscans. Oceanologia Et Limnologia Sinica 33(1), 90–96.

Li, D.H., Ganczarczyk, J.J., Jenkins, D., 1986. Physical characteristics of activated sludge flocs. Critical Reviews in Environmental Science and Technology 17(1), 53–87.

Liao, I.C., Chien, Y.H., 2011. The pacific white shrimp, Litopenaeus vannamei, in Asia: The world's most widely cultured alien crustacean. In In the wrong place-alien marine crustaceans: Distribution, biology and impacts (489–519). Dordrecht: Springer Netherlands.

Lin, Y.C., Chen, J.C., 2003. Acute toxicity of nitrite on *Litopenaeus vannamei* (Boone) juveniles at different salinity levels. Aquaculture 224(1–4), 193–201.

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.

Long, L., Yang, J., Li, Y., Guan, C., Wu, F., 2015. Effect of biofloc technology on growth, digestive enzyme activity, hematology, and immune response of genetically improved farmed tilapia (*Oreochromis niloticus*). Aquaculture 448, 135–141.

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, 1–7.

Mabroke, R.S., 2018. Complexity of carbon sources and the impact on biofloc integrity and quality in tilapia (*Oreochromis niloticus*) tanks. AACL Bioflux, 11(3).

Mahanand, S.S., Moulick, S., Rao, P.S., 2013. Water quality and growth of Rohu, Labeo rohita, in a biofloc system. Journal of Applied Aquaculture 25(2), 121–131.

Manan, H., Moh, J.H.Z., Kasan, N.A., Suratman, S., Ikhwanuddin, M., 2017. Identification of biofloc microscopic composition as the natural bioremediation in zero water exchange of Pacific white shrimp, *Penaeus vannamei*, culture in closed hatchery system. Applied Water Science 7, 2437–2446.

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 Immunology 64, 202–209.

Martı´nez-Co´rdova, L.R., Villarreal-Colmenares, H., Antonio Porchas-Cornejo, M.A., Naranjo-Paramo, J.A., 1997. Effect of aeration rate on growth, survival and yield of white shrimp *Penaeus vannamei* in low water exchange ponds. Aquacultural Engineering 16, 85–90.

Martínez-Córdova, L.R., Martínez-Porchas, M., Emerenciano, M.G.C., Miranda-Baeza, A., Gollas-Galván, T., 2017. From microbes to fish the next revolution in food production. Critical Reviews in Biotechnology 37(3), 287–295.

Martins, G.B., Tarouco, F., Rosa, C.E., Robaldo, R.B., 2017. The utilization of sodium bicarbonate, calcium carbonate or hydroxide in biofloc system: water quality, growth performance and oxidative stress of Nile tilapia (*Oreochromis niloticus*). Aquaculture 468, 10–17.

Martins, M.A., Poli, M.A., Legarda, E.C., Pinheiro, I.C., Carneiro, R.F.S., Pereira, S.A., Martins, M.L., Gonçalves, P., Schleder, D.D., do Nascimento Vieira, F., 2020. Heterotrophic and mature biofloc systems in the integrated culture of Pacific white shrimp and Nile tilapia. Aquaculture 514, 734517.

Matozzo, V., Gallo, C., Marin, M.G., 2011. Effects of temperature on cellular and biochemical parameters in the crab Carcinus aestuarii (Crustacea, Decapoda). Marine Environmental Research 71(5), 351–356.

McGraw, W., Variadas, T., 2003. Use of heterotrophic and autotrophic bacteria in aquaculture. Nicovita Newsletters. January–March, 1–3.

McIntosh, R.P., 2000. Changing paradigms in shrimp farming: IV. Low protein feeds and feeding strategies. Global Aquaculture Advocate 3(2), 44–50.

McKinnon, A.D., Trott, L.A., Alongi, D.M., Davidson, A., 2002. Water column production and nutrient characteristics in mangrove creeks receiving shrimp farm effluent. Aquaculture Research 33(1), 55–73.

McMillan, J.D., Wheaton, F.W., Hochheimer, J.N., Soares, J., 2003. Pumping effect on particle sizes in a recirculating aquaculture system. Aquacultural Engineering 27(1), 53–59.

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. Journal of the Arabian Aquaculture Society 5(2), 119–142.

Mehrim, A.I., 2009. Effect of dietary supplementation of Biogen® (Commercial probiotic) on mono-sex Nile tilapia Oreochromis niloticus under different stocking densities. Journal of Fisheries and Aquatic Science 4(6), 261–273.

Menaga, M., Fitzsimmons, K., 2017. Growth of the tilapia industry in India. World Aquaculture 48(3), 49–52.

Menaga, M., Felix, S., Charulatha, M., Gopalakannan, A., Mohanasundari, C., Boda, S., 2020. In vivo efficiency of Bacillus sp. isolated from biofloc system on growth, haematological, immunological and antioxidant status of genetically improved farmed tilapia (GIFT). Indian Journal of Experimental Biology (IJEB) 58(10), 714–721.

Midlen, A., Redding, T., 1998. Environmental management for aquaculture. Kluwer Academic Publishers, The Netherlands

Milstein, A., 1992. Ecological aspects of fish species interactions in polyculture ponds. Hydrobiologia 231(3), 177–186.

Moss, S.M., Divakaran, S., Kim, B.G., 2001. Stimulating effects of pond water on digestive enzyme activity in the Pacific white shrimp, *Litopenaeus vannamei* (Boone). Aquaculture Research 32(2), 125–131.

Muangkeow, B., Ikejima, K., Powtongsook, S. and Yi, Y., 2007. Effects of white shrimp, *Litopenaeus vannamei* (Boone), and Nile tilapia, *Oreochromis niloticus* L., stocking density on growth, nutrient conversion rate and economic return in integrated closed recirculation system. Aquaculture 269(1–4), 363–376.

Mueller, J.A., Morand, J., Boyle, W.C., 1967. Floc sizing techniques. Applied Microbiology 15(1), 125–134.

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 Physiology and Biochemistry 42, 457–465.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. Nature 405(6790), 1017–1024.

Ngasotter, S., Panda, S.P., Mohanty, U., Akter, S., Mukherjee, S., Waikhom, D., Devi, L.S., 2020. Current scenario of fisheries and aquaculture in India with special reference to Odisha: a review on its status, issues and prospects for sustainable development. International Journal of Bio-resource and Stress Management 11(4), 370–380.

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

Panigrahi, A., Sundaram, M., Chakrapani, S., Rajasekar, S., Syama Dayal, J. and Chavali, G., 2019. Effect of carbon and nitrogen ratio (C: N) manipulation on the production performance and immunity of Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) in a biofloc-based rearing system. Aquaculture Research 50(1), 29–41.

Panigrahi, A., Sundaram, M., Saranya, C., Kumar, R.S., Dayal, J.S., Saraswathy, R., Otta, S.K., Anand, P.S., Rekha, P.N., Gopal, C., 2019. Influence of differential protein levels of feed on production performance and immune response of pacific white leg shrimp in a biofloc–based system. Aquaculture 503, 118–127.

Panigrahi, A., Sundram, M., Jebha, J., Dayal, J.S., Otta, S.K., Bhuvaneswari, T., Saraswathy, R., Anand, P.S., Babu, D.R., Saranya, C., Gopal, C., 2017. Biofloc based nutrient dense culture system for nursery and grow-out farming of Pacific white shrimp *Penaeus vannamei* Boone, 1931. Indian Journal of Fisheries 64, 22–32.

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.

Perschbacher, P.W., Lorio, W.J., 1993. Filtration rates of catfish pond phytoplankton by Nile tilapia *Oreochromis niloticus*. Journal of the World Aquaculture Society

24(3), 434–437.

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

Pitt, R., Nguyen, D.Q.D., 2004. Breeding and rearing of the sea cucumber Holothuria scabra in Viet Nam. In: Lovatelli, A., Conand, C., Purcell, S., Uthicke, S., Hamel, J.F., Mercier, A. (Eds), Advances in sea cucumber aquaculture and management: FAO Fisheries Technical Paper 463, 333–346. FAO, Rome.

Poli, M.A., Legarda, E.C., de Lorenzo, M.A., Martins, M.A., do Nascimento Vieira, F., 2019. Pacific white shrimp and Nile tilapia integrated in a biofloc system under different fish-stocking densities. Aquaculture 498, 83–89.

Porchas-Cornejo, M.A., Martínez-Córdova, L.R., Ramos-Trujillo, L., Hernández-López, J., Martínez-Porchas, M., Mendoza-Cano, F., 2011. Effect of promoted natural feed on the production, nutritional, and immunological parameters of *Litopenaeus vannamei* (Boone, 1931) semi-intensively farmed. Aquaculture Nutrition 17(2), e622–e628.

Rakocy, J.E., 1997. Integrating tilapia culture with vegetable hydroponics in recirculating systems. Tilapia Aquaculture in the Americas 1, 163–184.

Rambhaskar, B., Srinivasa Rao, K., 1987. Comparative haematology of ten species of marine fish from Visakhapatnam Coast. Journal of Fish Biology 30(1), 59–66.

Ray, A.J., Lewis, B.L., Browdy, C.L., Leffler, J.W., 2010. Suspended solids removal to improve shrimp (*Litopenaeus vannamei*) production and an evaluation of a plant-based feed in minimal-exchange, super intensive culture systems. Aquaculture 299(14), 89–98.

Reinoso, S., Muñoz, D., Cedeño, R., Tirado, J.O., Bangeppagari, M., Mulla, S.I., 2019. Adaptation of" biofloc" aquatic system for polyculture with tilapia (*Oreochromis* sp.) and river prawn (*Macrobrachium* sp.). The Journal of Microbiology, Biotechnology and Food Sciences 8(5), 1130.

Roberto, H.E., Andrea, R.M., Osiris, R.M., del Carmen, M.D.M., 2017. Ecological succession of plankton in a biofloc system with molasses as carbon source. Scientific Journal of Biological Sciences 6(7), 222–228.

Rodrıguez, J., Le Moullac, G., 2000. State of the art of immunological tools and health control of penaeid shrimp. Aquaculture 191(1–3), 109–119.

Rouse, D.B., El Naggar, G.O., Mulla, M.A., 1987. Effects of stocking size and density of tilapia on *Macrobrachium rosenbergii* in polyculture. Journal of the World Aquaculture Society 18(2), 57–60.

Sakr, E.M., Shalaby, S.M., Wassef, E.A., El-Sayed, A.F.M., Moneim, A.I.A., 2015. Evaluation of periphyton as a food source for Nile tilapia (*Oreochromis niloticus*) juveniles fed reduced protein levels in cages. Journal of Applied Aquaculture 27(1), 50–60.

Samocha, T.M., Lawrence, A.L., Collins, C.A., Castille, F.L., Bray, W.A., Davies, C.J., Lee, P.G., Wood, G.F., 2004. Production of the Pacific white shrimp, Litopenaeus vannamei, in high-density greenhouse-enclosed raceways using low salinity groundwater. Journal of Applied Aquaculture 15(3–4), 1–19.

Santos, M.J.D., Valenti, W.C., 2002. Production of Nile tilapia Oreochromis niloticus and freshwater prawn *Macrobrachium rosenbergii* stocked at different densities in polyculture systems in Brazil. Journal of the World Aquaculture Society 33(3), 369–376.

Sayed, A.E.D.H., Moneeb, R.H., 2015. Hematological and biochemical characters of monosex tilapia (*Oreochromis niloticus*, Linnaeus, 1758) cultivated using methyltestosterone. The Journal of Basic & Applied Zoology 72, 36–42.

Sgnaulin, T., Durigon, E.G., Pinho, S.M., Jerônimo, G.T., de Alcantara Lopes, D.L., Emerenciano, M.G.C., 2020. Nutrition of genetically improved farmed tilapia (GIFT) in biofloc technology system: Optimization of digestible protein and digestible energy levels during nursery phase. Aquaculture 521, 734998.

Shigueno, K., 1975. Shrimp culture in Japan. Assoc. Int. Tech. Prom., Tokyo, 153.

Simão, B.R., Brito, L.O., Maia, A.S.C., Miranda, L.C., Azevedo, C.M.D.S.B., 2013. Stocking densities and feeding strategies in shrimp and tilapia polyculture in tanks. Pesquisa Agropecuária Brasileira 48, 1088–1095.

Skjervold, P.O., Fjæra, S.O., Østby, P.B., Einen, O., 2001. Live-chilling and crowding stress before slaughter of Atlantic salmon (*Salmo salar*). Aquaculture 192 (2–4), 265–280.

Smith, P.G., Coackley, P., 1984. Diffusivity, tortuosity and pore structure of activated sludge. Water research 18(1), 117–122.

Stuart, K., Paquette, M., Drawbridge, M., 2009. Integrated larval-nursery system for California halibut. Global Aquaculture Advocate, 12.

Sundaram, M., Sivakumar, R. M., Saranya, C., Krishna, A., Anand P. S. S., Christina, L., Antony, J., Panigrahi, A., 2021. The effect of natural and artificial periphytic substrates with biofloc system on shrimp *Penaeus vannamei* (Boone 1931) culture: growth and immune response. Aquaculture International 29, 651–668. https://doi.org/10.1007/s10499-021-00646-0.

Svobodova, Z., Kroupova, H., Modra, H., Flajšhans, M., Randak, T., Savina, L.V., Gela, D., 2008. Haematological profile of common carp spawners of various breeds. Journal of Applied Ichthyology 24(1), 55–59.

Tadesse, Z., 1999. The nutritional status and digestibility of *Oreochromis niloticus* L. diet in Lake Langeno, Ethiopia. Hydrobiologia 416(0), 97–106.

Tendencia, E.A., dela Peña, M., 2003. Investigation of some components of the greenwater system which makes it effective in the initial control of luminous bacteria. Aquaculture 218(1–4), 115–119.

Tendencia, E.A., dela Peña, M.R., Choresca Jr, C.H., 2006. Effect of shrimp biomass and feeding on the anti-*Vibrio harveyi* activity of Tilapia sp. in a simulated shrimp–tilapia polyculture system. Aquaculture 253(1–4), 154–162.

Tendencia, E.A., dela Peña, M.R., Fermin, A.C., Lio-Po, G., Choresca Jr, C.H., Inui, Y., 2004. Antibacterial activity of tilapia Tilapia hornorum against *Vibrio harveyi*. Aquaculture 232(1–4), 145–152.

Tendencia, E.A., Fermin, A.C., dela Peña, M.R., Choresca Jr, C.H., 2006. Effect of *Epinephelus coioides, Chanos chanos*, and GIFT tilapia in polyculture with Penaeus monodon on the growth of the luminous bacteria *Vibrio harveyi*. Aquaculture 253(1–4), 48–56.

Tian, X., Li, D., Dong, S., Yan, X., Qi, Z., Liu, G., Lu, J., 2001. An experimental study on closed-polyculture of penaeid shrimp with tilapia and constricted tagelus. Aquaculture 202 (1–2), 57–71.

Tidwell, J.H., Coyle, S.D., Bright, L.A., 2010. Polyculture of Nile tilapia, Oreochromis niloticus, either confined in cages or unconfined in freshwater prawn, Macrobrachium rosenbergii, ponds. Journal of the World Aquaculture Society 41(4), 616–625.

Tidwell, J.H., Coyle, S.D., VanArnum, A., Weibel, C., Harkins, S., 2000. Growth, survival, and body composition of cage-cultured Nile tilapia Oreochromis niloticus fed pelleted and unpelleted distillers grains with solubles in polyculture with freshwater prawn Macrobrachium rosenbergii. Journal of the World Aquaculture Society 31(4), 627–631.

Timmis, K., De Vos, W.M., Ramos, J.L., Vlaeminck, S.E., Prieto, A., Danchin, A., Verstraete, W., De Lorenzo, V., Lee, S.Y., Brüssow, H., Timmis, J.K., 2017. The contribution of microbial biotechnology to sustainable development goals. Microbial Biotechnology 10(5), 984–987.

Tong, R., Chen, W., Pan, L., Zhang, K., 2020. Effects of feeding level and C/N ratio on water quality, growth performance, immune and antioxidant status of Litopenaeus vannamei in zero–water exchange bioflocs - based outdoor soil culture ponds. Fish & Shellfish Immunology 101, 126–134.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A.H., Fang, J.G., 2009. Ecological engineering in aquaculture-potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture 297(1–4), 1–9.

Van Wyk, P., 2006. Production of *Litopenaeus vannamei* in recirculating aquaculture systems: Management and design considerations. In Proceedings of the 6th International Conference in Recirculating Aquaculture (38–47). Virginia Tech University, Blacksburg, VA, USA.

Verdegem, M., Buschmann, A.H., Latt, U.W., Dalsgaard, A.J., Lovatelli, A., 2023. The contribution of aquaculture systems to global aquaculture production. Journal of the World Aquaculture Society 54(2), 206–250.

Vinatea, L., Gálvez, A.O., Browdy, C.L., Stokes, A., Venero, J., Haveman, J., Lewis, B.L., Lawson, A., Shuler, A., Leffler, J.W., 2010. Photosynthesis, water respiration and growth performance of *Litopenaeus vannamei* in a super-intensive raceway culture with zero water exchange: interaction of water quality variables. Aquacultural Engineering 42(1), 17–24.

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. Aquaculture Research 47(10), 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.

Wang, J.Q., Li, D., Dong, S., Wang, K., Tian, X., 1998. Experimental studies on polyculture in closed shrimp ponds: I. Intensive polyculture of Chinese shrimp (*Penaeus chinensis*) with tilapia hybrids. Aquaculture 163(1–2), 11–27.

Wang, M., Lu, M., 2016. Tilapia polyculture: a global review. Aquaculture Research 47(8), 2363–2374.

Wasielesky Jr, W., Atwood, H., Stokes, A., Browdy, C.L., 2006. Effect of natural production in a zero exchange suspended microbial floc based super-intensive culture system for white shrimp *Litopenaeus vannamei*. Aquaculture 258(1–4), 396–403.

Weber, S.E., Shelton, J.L., Roberts, H.E., 2009. Environment and husbandry: ponds and aquaria. In: Roberts, H.E. (Ed.), Fundamentals of ornamental fish health. Wiley-Blackwell, Ames (IA), 172–184.

Wilén, B.M., Balmer, P., 1999. The effect of dissolved oxygen concentration on the structure, size and size distribution of activated sludge flocs. Water Research 33(2), 391–400.

Wilén, B.M., Nielsen, J.L., Keiding, K., Nielsen, P.H., 2000. Influence of microbial activity on the stability of activated sludge flocs. Colloids and Surfaces B: Biointerfaces 18(2), 145–156.

Wohlfarth, G.W., Hulata, G., Karplus, I., Halevy, A., 1985. Polyculture of the freshwater prawn *Machrobrachium rosenbergii* in intensively manured ponds, and the effect of stocking rate of prawns and fish on their production characteristics. Aquaculture 46(2), 143–156.

Wyban, J., Sweeney, J.N., 1991. Intensive shrimp production technology: the Oceanic Institute shrimp manual. Makapuu Point, Honolulu, Hawaii

Xu, X., 2013. Technology of polyculture of tilapia with large yellow croaker in ponds. Anhui Agriculture (Chinese) 2, 262–265

Xu, W., Xu, Y., Su, H., Hu, X., Xu, Y., Li, Z., Wen, G., Cao, Y., 2021. Production performance, inorganic nitrogen control and bacterial community characteristics in a controlled biofloc-based system for indoor and outdoor super-intensive culture of *Litopenaeus vannamei*. Aquaculture 531, 735–749.

Xu, W.J., Pan, L.Q., 2012. Effects of bioflocs on growth performance, digestive enzyme activity and body composition of juvenile *Litopenaeus vannamei* in zero-water exchange tanks manipulating C/N ratio in feed. Aquaculture 356, 147–152.

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, 117–124.

Xu, W.J., Pan, L.Q., Sun, X.H., Huang, J., 2013. Effects of bioflocs on water quality, and survival, growth and digestive enzyme activities of *Litopenaeus vannamei* (Boone) in zero-water exchange culture tanks. Aquaculture Research 44(7), 1093–1102.

Yakupitiyage, A., Edwards, P., Wee, K.L., 1991. Supplementary feeding of fish in a duck–fish integrated system. I. The effect of rice-bran. In Fish Nutrition Research in Asia. Proceedings of the Fourth Asian Fish Nutrition Workshop. Asian Fisheries Society Special Publication 5, 143–157.

Yi, Y., Saelee, W., Naditrom, P., Fitzsimmons, K., 2002. Stocking densities for tilapia-shrimp polyculture in Thailand. Twentieth Annual Technical Report, Pond dynamics/Aquaculture Collaborative Research Support Program, Oregon State University, Corvallis, Oregon.

Yokoyama, H., Higano, J., Adachi, K., Ishihi, Y., Yamada, Y., Pichitkul, P., 2002. Evaluation of shrimp polyculture system in Thailand based on stable carbon and nitrogen isotope ratios. Fisheries Science 68(4), 745–750.

Yu, Y.B., Choi, J.H., Lee, J.H., Jo, A.H., Lee, K.M., Kim, J.H., 2023. Biofloc technology in fish aquaculture: A review. Antioxidants 12(2), 398.

Yu, Z., Huang, Z.Q., Du, H.L., Li, H.J., Wu, L.F., 2020. Influence of differential protein levels of feed on growth, copper-induced immune response and oxidative stress of *Rhynchocypris lagowski* in a biofloc-based system. Aquaculture Nutrition 26(6), 2211–2224.

Yuan, D., Yi, Y., Yakupitiyage, A., Fitzimmons, K., Diana, J.S., 2010. Effects of addition of red tilapia (*Oreochromis* spp.) at different densities and sizes on production, water quality and nutrient recovery of intensive culture of white shrimp (*Litopenaeus vannamei*) in cement tanks. Aquaculture 298(3–4), 226–238.

Zaki, M.A., Alabssawy, A.N., Nour, A.E.A.M., El Basuini, M.F., Dawood, M.A., Alkahtani, S., Abdel-Daim, M.M., 2020. The impact of stocking density and dietary carbon sources on the growth, oxidative status and stress markers of Nile tilapia (*Oreochromis niloticus*) reared under biofloc conditions. Aquaculture Reports 16, 100282.

Zhao, P., Huang, J., Wang, X.H., Song, X.L., Yang, C.H., Zhang, X.G., Wang, G.C., 2012. The application of bioflocs technology in high-intensive, zero exchange farming systems of *Marsupenaeus japonicus*. Aquaculture 354, 97–106.

Zhen-xiong, Q., De-shang, L., Man-ping, Z., Shuang-lin, D., 2001. Comparative studies on nitrogen budgets of closed shrimp polyculture systems. Chinese Journal of Oceanology and Limnology 19, 233–242.

Zhou, X., Li, M., Abbas, K., Wang, W., 2009. Comparison of haematology and serum biochemistry of cultured and wild Dojo loach *Misgurnus anguillicaudatus*. Fish physiology and Biochemistry 35, 435–441.

Zhu, X.Z., Liu, Y.J., Tian, L.X., Mai, K.S., Zheng, S.X., Pan, Q.J., Cai, M.C., Zheng, C.Q., Zhang, Q.H., Hu, Y., 2010. Effects of dietary protein and lipid levels on growth and energy productive value of pacific white shrimp, *Litopenaeus vannamei*, at different salinities. Aquaculture Nutrition 16(4), 392–399.

Zimmermann, S., New, M.B., 2000. Grow-out systems polyculture and integrated culture. Freshwater prawn farming: The farming of *Macrobrachium rosenbergii*. England: Blackwell Science, 187–202.