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AQUAMIMICRY SYSTEM: A SUITABLE STRATEGY FOR SHRIMP AQUACULTURE – A REVIEW

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Abstract

Shrimp culture is the most lucrative sector in aquaculture industry; however, for its sustainable development the environment conservation should be considered. New developed technologies are required for aquaculture to achieve its sustainable goals. Among the different novel sustainable technologies, the biofloc technology (BFT) and more recently the aquamimicry system are considered as reliable methods in burgeoning development of shrimp culture. The establishment of the BFT needs a certain carbon to nitrogen (C: N) ratio so that heterotrophic bacteria are able to utilize nitrogenous metabolites, and preserve the water quality in the standard ranges suitable for shrimp culture. In addition, the produced floc can be used as supplementary food for shrimp. On the other hand, the establishment of the aquamimicry system relies on organic carbon without providing a specific C: N ratio. In this system, a synergistic relationship between a prebiotic source, which usually consists of an oligosaccharide derived from the fermentation of a carbon source (*e.g.*, rice bran), and a probiotic source such as *Bacillus* sp. can provide natural conditions by blooming phytoplankton and zooplankton organisms, especially copepods. These live foods can be used as complementary foods for shrimp. Furthermore, the proliferation of beneficial bacteria in the aquamimicry system can provide stable culture condition for growth and welfare of shrimp. Based on the findings of recent literature, using the aquamimicry system for shrimp production is more sustainable, eco-friendly, and greener than the conventional systems.

Key words: aquaculture, aquamimicry, shrimp, fermentation, microbial communities, probiotics

Crustacean culture with an annual production of 9.4 million tons in 2018 was the third largest productive sector among different aquaculture activities. In addition, it is the most lucrative sectors of aquaculture with the sale value of USD 69.3 billion in 2018 (FAO, 2020). Among various farmed crustacean species, Pacific white shrimp, *Penaeus vannamei* (59.2% of total crustacean production) and giant tiger prawn, *Penaeus monodon* (8.0% of total crustacean production) comprised about 67% of the total crustacean production in 2018 (FAO, 2020). However, the shrimp farming industry had catastrophic environmental effects on the coastal areas, especially in countries located in Southeast Asia (Anh et al., 2010). As shrimp culture industry has become more intensive to meet high market demands for this luxurious protein source, traditional farms discharge large volumes of wastes such as uneaten feed, fertilizers, metabolic excretions, and therapeutics among the others (Iber and Kasan, 2021). As a result of the aquaculture intensification and indiscriminate usage of therapeutics, the water quality has deteriorated and may exceed the environmental standards.

In order to ensure the sustainable production with environmental concerns, green and organic technologies must be developed (Kumar et al., 2018). During the past few years, technological innovations have been used to minimize detrimental environmental impacts, increase biosecurity and reduce shrimp production costs. In addition, there are several strategies to manage shrimp aquaculture waste water, and its treatment such as high rate algal pond system, use of nanomaterials (*e.g.,* nanoadsorbents, nanofiber membranes, polymeric nanoadsorbents, and nanomaterial based membranes), bioaugmentation technology, solid state thermophilic aerobic fermentation for recovery of nutrients from waste water, and *in situ* water bioremediation technologies (*e.g.,* biofloc technology, BFT) (Iber and Kasan, 2021). The BFT and aquamimicry systems are considered as promising methods for the sustainability of shrimp aquaculture industry (Khanjani and Sharifinia, 2020; Santhanam et al., 2020).

In the BFT system, stimulating the proliferation of heterotrophic bacteria (HTB) increases the absorption of inorganic nitrogen that can be achieved by adjusting the carbon to nitrogen (C: N) ratio to 15: 1. The formation of biofloc in the BFT also provides supplementary nutrients for growth and reduces the amount of feed used in shrimp aquaculture (Emerenciano et al., 2012; Esparza-Leal et al., 2015; Gaona et al., 2016; Khanjani et al., 2020; Khanjani and Sharifinia, 2021). In this context, Brito et al. (2014) reported that *P. vannamei* farming in the BFT improved growth performance, and reduced total ammonia nitrogen, nitrite, and harmful opportunistic bacteria such as *Vibrio* sp. in the culture media. Furthermore, the BFT is a highly productive system, with a production rate of 17.8 tons/hectare (Kumar et al., 2018). Moreover, the rate of water exchange in the BFT is limited, effluent is minimized, and as a result, the environmental damages are alleviated (Bauer et al., 2012; Khanjani and Sharifinia, 2022; Khanjani et al., 2022 a). Despite its several privileges, the BFT has its own limitations including high aeration to maintain suspended particles in the water column, high infrastructure and installation expenditures, great energy consumption, high carbon fingerprint, and the complicated management of total suspended solids in the system (Gaona et al., 2016; Romano, 2017).

Compared to the BFT, aquamimicry is a new shrimp farming method that can be used to overcome these limitations by modulating the conventional methods. In recent years, several countries have adapted this expertise in shrimp farming, including Thailand, Australia, Bangladesh, Brazil, Brunei, China, Ecuador, Egypt, India, Korea, Malaysia, Mexico, Peru, Singapore, Sri Lanka, USA, and Vietnam (Zeng et al., 2020). Aquamimicry technique can simulate natural condition for shrimp farming by stimulating the microbial growth, flourishing phyto- and zooplankton populations, especially copepods, that can be used as complementary foods and can provide *in situ* water quality maintenance (Romano, 2017). This technique mimics the natural environment, creates environmental stability, and reduces the cost of feeding (Panigrahi et al., 2019; Deepak et al., 2020; Nisar et al., 2022). The information regarding the aquamimicry method, its benefits, or how it compares with the BFT is scarce. Thus, the present review attempted to focus on the essence of the aquamimicry technique mainly in the following items:

- Aquamimicry system definition,
- Differences and similarities between the BFT and aquamimicry systems,
- The advantages of aquamimicry system,
- The importance of the fermentation process in aquamimicry system,
- The application of probiotics in aquamimicry system,
- Live foods in aquamimicry system,
- Microbial communities in aquamimicry systems,
- Shrimp farming protocol in aquamimicry system,
- Other benefits of aquamimicry aquaculture system,
- The challenges ahead and future perspective,
- Conclusion.

Aquamimicry system definition

The aquamimicry technique was established in 2013 by two longtime shrimp farmers in Thailand, namely Sutee Prasertmark and Veerasan Prayotamornkul. This method is based on the hypothesis that the shrimp farming practices can be more sustainable by mimicking the natural aquatic environment in the aquaculture condition. This system is a balanced and cost-effective approach based on the simulation of natural conditions by nourishing shrimps with zooplanktons, and using beneficial bacteria to improve water quality (Romano, 2017; Nisar et al., 2022). The success of this method is dependent on the use of carbon sources such as rice bran, soybean, and wheat meals combined with the application of probiotics that pronouncedly enhance the bloom of zooplanktons. Thus, in the presence of the live foods, especially copepods that are rich in long-chain polyunsaturated fatty acids (LC-PUFA), minerals, trace elements, pigments, and pool of free amino acids (e.g., taurine) may improve feed efficiency, and enhance the shrimps' immunocompetence (Conceição et al., 2010; Biesebeke, 2018; Butto and Haller, 2016). In addition, in aquamimicry method, the addition of fermented carbon sources as well as probiotics can promote water quality, and facilitate the recycling of nitrogenous metabolites in the system (Panigrahi et al., 2019; Deepak et al., 2020; Nisar et al., 2022). The aquamimicry technique by creating a synbiotic relation between fermented carbon sources derivatives (*e.g.,* oligosaccharides) and probiotics (*e.g., Bacillus* species), reduces the application of therapeutics, and contributes to green aquaculture (Butto and Haller, 2016; Biesebeke, 2018; Deepak et al., 2020; Santhanam et al., 2020; Zeng et al., 2020).

Differences and similarities between the BFT and aquamimicry systems

Aquamimicry and the BFT have some major similarities, but they also have some differences as well. Biofloc technology and aquamimicry systems both require the inclusion of external carbon sources. Carbon sources are used as substrates for establishing the BFT and the production of microbial protein cells (Avnimelech, 2007; Khanjani et al., 2022 a, b). Inexpensive carbon sources are typically obtained from crops, and livestock feed products such as molasses, glycerol, and cereals (*e.g.,* wheat, corn, rice). For the maintenance of the BFT, the optimal proliferation and growth of HTB, a C: N ratio near 15: 1 is needed (Emerenciano et al., 2012; Khanjani et al., 2021 a, b, c). Heterotrophic bacteria absorb nutrients, and optimize the formation of flocs by consuming energy derived from carbohydrate sources (Avnimelech, 1999; Asaduzzaman et al., 2008). The carbon source is used before stocking of shrimp post-larvae (PL), and during the grow-out phase to maintain a high C: N ratio around 15: 1 (El-Sayed, 2021). This technology limits

water exchange to reduce the toxic effects of nitrogenous metabolites accumulated during grow-out phase by *in situ* water bioremediation. A plethora of studies have shown that floc floccule which is the collection of uneaten feed, feces, detritus and attached organisms (*e.g.,* bacteria, filamentous cyanobacteria, protozoa, nematodes, phytoplankton and fungi) can be used as a supplementary food source for shrimp, and thus could spare dietary protein and reduce feed costs (Hari et al., 2004; Asaduzzaman et al., 2008; Avnimelech, 2009; Crab et al., 2012; Khanjani and Sharifinia, 2020). In contrast, in aquamimicry method it is not necessary to adjust the C: N ratio and its ratio is mainly dependent on the water turbidity level. In this system for enhancing the production of floc, more probiotics can be included during the grow-out phase that maintain beneficial bacterial colonies to improve water quality (Catalani, 2020; Deepak et al., 2020; Zeng et al., 2020). In addition, in this system by optimizing the balance between phyto- and zooplankton through the inclusion of fermented carbon sources, the pH and dissolved oxygen fluctuations are minimized which reduces the need for using chemicals (Romano, 2017).

The main differences between the BFT and aquamimicry systems are:

1) The inclusion of a carbon source to the aquamimicry system has nothing to do with the amount of nitrogen, but in the BFT the management of C: N ratio requires experience and should be considered at least above 10 to stimulate the activity of HTB (Khanjani and Sharifinia, 2020, 2022; Nisar et al., 2022),
2) The role of zooplanktons in the aquamimicry system is greater than that in the BFT,
3) A fermented carbon source is required for establishing the aquamimicry system.

The advantages of aquamimicry system

The advantages of aquamimicry system in shrimp aquaculture are:

- Culture in this system is more stable than the conventional systems,
- Farmed shrimp are healthier due to the presence of bacterial secondary metabolites such as liposaccharides, and peptidoglycans present in probiotics can boost up animals' immunocompetence (Kim et al., 2014; Huynhtg et al., 2017),
- Feed conversion ratio improvement due to the abundance of zooplanktons, especially copepods,
- Reduces the likelihood of disease outbreaks by providing more natural condition and welfare,
- It can be used for large and semi-intensive cultivation systems that can reduce feed consumption and water exchange rates (Catalani, 2020; Deepak et al., 2020),
- Improves the overall nutrition of farmed shrimp due to the presence of live foods in the culture media,
- Alleviates stress condition in farmed shrimp and enhance biosecurity by limiting water exchange rate,
- It provides unfavorable condition for propagation of harmful bacterial pathogens and the formation of black soil can be reduced,
- Using this method can increase the shrimp production yield, reduce expenditures, and enhance profitability. The production of suspended solids and wastes in aquamimicry system reduces the dependency on commercial feeds that decreases the amount of biological oxygen demand, and the need for intense aeration that enhances the efficiency of energy consumption (Romano, 2017),
- In this method, simulating culture in natural condition can trigger better growth performance in shrimps,
- The aquamimicry system requires less technology, infrastructure and knowledge for establishment and operation and can be implemented by aquaculture farmers with a lower technical level.

The importance of the fermentation process in aquamimicry system

Fermentation is a biotechnological process that improves the utilization efficiency of lignocellulosic materials by degrading these complex compounds into simpler forms and in turn can lead to higher nutrients bioavailability, digestion and growth rates in animals (Suprayudi et al., 2012; Mulyasari and Setiawati, 2013; Razak et al., 2017). This microbial process usually applies in aquaculture for increasing the nutritional value, and decreasing the anti-nutritional factors (ANF) in alternative protein sources, and cereals for inclusion into feed formulation (Dawood and Koshio, 2020). Cereals contain low amounts of some essential amino acids (*e.g.,* methionine, lysine and tryptophan), high fiber levels and ANF that cause poor digestion and growth. The fermentation process can reduce the amount of undesirable substances and enriches the nutritional quality of plant proteins and cereals by activity of microbial derived enzymes in an anaerobic condition (Shi et al., 2015; Jannathulla et al., 2017; Qiu and Davis, 2018). In this process, microorganisms (*e.g.,* bacteria, fungi, and yeast) use carbohydrates as an energy source, and convert them into microbial proteins. This process reduces the amount of fiber and ANF while increasing amino acids, vitamins, minerals and proteins in fermented products (Jannathulla et al., 2017; Qiu and Davis, 2018). It has been confirmed that the use of probiotics with fermented grains in shrimp farming significantly improved the digestion (Lara-Flores, 2011). Furthermore, dietary fishmeal can be partially replaced by fermented cereals meal in shrimp feed and it has higher digestibility and is more nutritious compared to non-fermented cereals (Jannathulla et al., 2019). Among various cereals, rice bran is an agricultural waste that is commonly used as a source of carbon and energy in aquafeeds. This carbon material is cheaply available and can be easily obtained from the market, contains significant amounts of nutrients, and has a relatively high fiber content (Deepak et al., 2020). Rice bran is preferably used

in fermented form, because in this form, not only it has higher nutritional value due to higher protein content and digestibility, but also its ANF, fat, ash, and phytic acid are reduced (Flores-Miranda et al., 2014; Albuquerque, 2019; Deepak et al., 2020). In Albuquerque (2019) study, biochemical compounds of rice bran after fermentation process were 16.79%, 14.92%, 17.36% and 50.94% for protein, fat, ash and total carbohydrates, respectively. Using rice bran as a fermentation medium increases the availability of nutrients and is a fast, low cost and low risk process. Microorganisms or enzymes can be used to facilitate the solubility of the carbon source in water. Fungi and bacteria have been reported to be involved in the production of hydrolytic enzymes that reduce fiber and carbohydrate contents and increase the protein solubility of carbon sources (Romano et al., 2018). The fiber in rice bran acts as a prebiotic and it can be fermented by probiotics in the animals' gut to produce short chain fatty acids (Zubaidah et al., 2012). In this context, the effects of *Bacillus subtilis*-fermented rice bran on water quality, performance, antioxidant activity and immunity of *L. vannamei* in different salinities with zero water exchange system were studied (Abdel-Tawwab et al., 2022). The results showed that water quality parameters (*e.g.,* alkalinity, total ammonia nitrogen and nitrite) were significantly improved. There was a significant increase in the number of beneficial bacteria such as *Bacillus* sp. and a decrease in pathogenic bacteria such as *Vibrio* sp. in the fermented rice bran based system. Furthermore, significant improvements in antioxidants, immune biomarkers, growth and productivity of *L. vannamei* were also noted in fermented rice bran based system at 35 g L^{-1} of salinity (Abdel-Tawwab et al., 2022). Moreover, fermented rice bran with *Bacillus* and *Lysinibacillus* sp. has altered the bacterial communities in hepatopancreas and improved the survival and growth rates in *L. vannamei* (Liñan-Vidriales et al., 2021). Figure 1 shows how to prepare it and Figure 2 shows how to use fermented rice bran in aquamimicry system.



Figure 1. Preparation of fermented rice bran. A: start of preparation (rice bran and probiotic). B: 24 hours after preparation. (Image: Catalani, 2020)



Figure 2. A: Anaerobic fermented rice bran maintained for 24 hours in an experiment on feed replacement. B: Application of fermented rice bran in pond during feed replacement experiment (Image: Gonçalves, 2022)

The application of probiotics in aquamimicry system

The use of probiotics in modern aquaculture is increasingly rising, which in addition to helping to preserve the gut microbiota (De et al., 2014) helps to promote the nutritional value of plant feedstuffs through fermentation (Van Nguyen et al., 2018). Their use in aquaculture systems such as the BFT and aquamimicry also improves the zootechnical process of the system (De Melo et al., 2015). Probiotics are living microorganisms that are added to the aquaculture environment through food or water to exert beneficial effects on the host health and its growth performance by modulating the gut microflora (Balcázar et al., 2006; Merrifield et al., 2010; Dawood et al., 2016, 2018; Vidal et al., 2018). The use of probiotics in aquaculture is a suitable alternative to therapeutics for controlling occurrences of infectious diseases and they can contribute to improve water quality (Liu et al., 2010; Jahangiri and Esteban, 2018; Biswas et al., 2019; Nathanailides et al., 2021).

Probiotics produce enzymes that limit the activity of pathogenic bacteria by reducing the gut's pH, making it difficult for these bacteria to live at low pH (Martínez Cruz et al., 2012). In addition, probiotics through quorum quenching mechanism can disturb quorum sensing among opportunistic bacteria that regulates virulence factors, and formation of biofilms, which are the critical parameters in occurrence of the infectious diseases in farmed aquatic animals (Jayaprakashvel and Subramani, 2019). Limiting the activity of pathogenic bacteria can provide a better environment for proliferation of beneficial microbes in the gut to improve digestion, and absorption of nutrients (Lara-Flores, 2011). Spore-forming gram-negative bacteria such as *Bacillus* species have been shown to be suitable probiotics for using in aquaculture, these probiotics can be easily stored at room temperature without compromising their biological function. Specific probiotics, including *B. subtilis*, produce essential vitamins such as vitamin B_1 and vitamin B_{12} (Ghosh et al., 2007). Therefore, these probiotics are increasingly used to enhance growth, resistance to pathogenic microbes in farmed shrimp, improve nutritional efficiency and feed conversion ratio, and reduce production costs (Vidal et al., 2018). In general, the addition of probiotics to the aquamimicry system has the following functions:

- Provides synbiotics effects along with derivatives of fermented carbon sources,
- Restricts the propagation of pathogenic bacteria through quorum quenching mechanism,
- Stimulates shrimps' immune system,
- Helps *in situ* water bioremediation,
- Enhances survival rate of shrimp's PL,
- Probiotics are environmental friendly and biodegradable supplements for broader activity spectrum,
- Reduces toxic gas, total suspended solid, biological and chemical oxygen demands, thereby increasing dissolve oxygen *in situ*.

Live foods in aquamimicry system

Aquamimicry technology is based on natural products, especially copepods, as feed for stocked shrimp, which is called copefloc technology (Santhanam et al., 2020; Deepak et al., 2020). In the aquamimicry method, copepods as the dominant species replace other zooplankton species indicating the maturity of the system (Chakravarty et al., 2018). Copepods are usually dominating in the aquamimicry system from the second week of cultivation (Romano and Kumar, 2017). Copepods are crustaceans that are widely used in nature due to their short life and small size, including food for marine animals, nutrient recycling and energy conversion in the food chain (Radhakrishnan et al., 2019; Chakravarty et al., 2018). The use of copepods is increasing in the aquaculture industry due to its appropriate biochemical compositions and helping to improve survival and growth in farmed shrimp at various life stages, including eggs, nauplius, pre-adults and adults (Drillet et al., 2011; Chakravarty et al., 2018; Drillet et al., 2006; Abbaszadeh et al., 2022). Copepods have a higher nutritional value than rotifer and *Artemia*, and they are naturally richer in LC-PUFA including eicosapentaenoic, docosahexaenoic, and arachidonic acids, which are essential for growth and development (Wilcox et al., 2006; Satoh et al., 2009). In addition, it has been confirmed that copepods contain high amounts of carotenoids, free amino acids (*e.g.,* taurine), peptides, vitamins and minerals (*e.g.,* selenium, iodine, copper and manganese) (Karlsen et al., 2015; Taher et al., 2017). Furthermore, various copepods varied significantly in protein levels, ranging between 52.4% and 57.6% of dry weight, compared with *Artemia franciscana* (41% in newly hatched nauplii and 34% after 24-h enrichment). Copepods' nauplius range in size from 50 to 60 µm, which are more suitable in size than rotifers and *Artemia* for larval stages of different farmed aquatic species with small mouth gape. Copepodites and adult stages are larger and have been used successfully to feed larger larvae (Leu et al., 2015). In this context, Martinez-Cordova et al. (2011) reported that the inclusion of copepods (*Acartia* sp., *Calanus pacificus*) significantly improved growth performance and survival rate in *L. vannamei* during the nursery phase in a microcosm system. In addition, Abbaszadeh et al. (2022) reported that inclusion of copepod (*Calanopia elliptica*, 0.2 organisms mL^{-1}) in a BFT nursery system remarkably improved growth, immune parameters and enhanced feed efficiency in *L. vannamei*. Environmental factors such as light, salinity, temperature and available nutrients can affect the abundance and the diversity of phytoplankton and zooplankton species in this system (Alonso-Rodriguez and Páes-Osuna, 2003). In the study by Catalani (2020), microorganism communities in two systems, BFT and aquamimicry were studied during 120 days of Pacific white shrimp farming. The results showed that the amounts of cyanobacteria and flagellates in the aquamimicry system are higher than the BFT, but the amounts of chlorophytes and diatoms were lower. At the beginning of the farming

period, the amount of rotifers and ciliates in the aquamimicry system were higher than that of the BFT. At the end of the period, rotifers and ciliates were absent in the aquamimicry system and flagellates were the dominant group. In this research, cyanobacteria bloomed in the middle of the rearing period in the aquamimicry system (Catalani, 2020). Cyanobacteria can produce toxins that adversely affect the physiology of shrimp and ultimately lead to high mortality (Gonçalves-Soares et al., 2012). The abundance of nutrients leads to changes in the dominant planktonic species in the rearing system, so that increasing the level of nutrients such as phosphate leads to an increase in flagellar density. A study by Teixeira et al. (2011) found that flagellar densities increase in systems that do not use a carbon source. Thus, in aquamimicry system, the inclusion of fermented carbon sources along with probiotics can balance the bloom and diversity of phyto- and zooplanktons and eventually provide a convenient condition for maximum growth and welfare of shrimps.

Microbial communities in aquamimicry systems

The management of microbial communities in the shrimp farming system is essential as it can prevent the occurrence of disease outbreaks. Aquamimicry may give us an idea of the healthy condition of shrimp culture based on the divergence between shrimps' gut and environmental microflora (Zeng et al., 2020). Microbial communities in the shrimp gut and its surroundings act as an essential component of the aquamimicry system and provide an ecological model for preventing disease outbreaks during farming. However, the information regarding microbial composition and changes in its diversity in shrimp gut in the aquamimicry system is scarce. The shrimp gut microbial diversity can be considered as a reliable indicator of the host health (Ren et al., 2018). It has been confirmed that the shrimp gut microflora, surrounding water, and sediment are similar in earthen ponds (Hou et al., 2018). Some studies have reported that shrimp gut microflora is little affected by the surrounding water, while being significantly associated with its life stage (Xiong et al., 2019, 2020). A study by Xiong et al. (2018) showed that shrimp can obtain a variety of bacterial species from the environment, although only a small fraction of the bacteria can successfully colonize shrimp gut.

In the study of Zeng et al. (2020), the composition and diversity of shrimp gut microbiota and environmental microbial communities (surroundings) in the aquamimicry system as well as the relationships between shrimp gut microbiota, water and sediments were investigated. Their results showed that the microbial diversity of the shrimp gut, surrounding water and sediment in the aquamimicry system were different. In their study, in three habitats microbial branches were found in different percentages, including: *Proteobacteria* (32%), *Bacteroides* (11%), *Patescibacteria* (9%), *Plancyomycetes* (8%), *Firmicutes* (7%), *Chloroflexi* (6%), *Actinobacteria* (5%), *Verrucomicrobia* (4%), *Cyanobacteria* (3%), *Acidobacteria* (2%) and other microbes (13%). In this system in shrimps' gut, the abundance of some opportunistic pathogens (such as *Aeromonas*, 0.5%; *Phascolarctobacterium*, <0.01%; *Photobacterium*, 0.4%) were low, while *Vibrio* (10.9%) and *Candidatus Bacilloplasma* (10.4%) were the dominant genera (Zeng et al., 2020). The dissimilarity of microbial diversity between different rearing systems can be a potential indicator of the health status of farmed shrimp and will be a good practical guide for sustainable shrimp production. These findings reinforce our understanding of the importance of microbial communities in the aquamimicry system and provide essential information for improving health and survival in shrimp farming.

Shrimp farming protocol in aquamimicry system

In the aquamimicry system, the most suitable source of identified carbon is rice bran, which is fermented by probiotics. Fermented rice bran can be made by adding water, probiotics and hydrolyzing enzymes to rice bran powder and allowed to ferment for 24 h. Here, rice bran acts as a prebiotic and has a synbiotic effect by adding probiotic bacteria. Fermented rice bran can be included into aquamimicry system at the rate of 500 to 1000 kg ha^{-1}. After a week, the flourishing of live foods, especially copepods, is observed. Prior to shrimp PL stocking, copepods are formed at a suitable density in the cultivation pond. Then, shrimp PL are stocked at a density of 10 to 20 organisms/m^{-2}. During the rearing period, a regular dose of fermented rice bran (usually 1.0 ml L^{-1}) is regularly added to the ponds daily to maintain zooplankton blooms as well as the formation of floc floccules. The turbidity level of the water in aquamimicry system determines the appropriate inclusion of FRB. Feeding will then be done with fermented soybean meal, that will reduce feed costs. Fermentation of soybean meal (SBM) can enhance its nutritional value, and its digestibility by providing low molecular weight peptides, elevating the bioavailability of minerals and reducing its ANF (Hong et al., 2004; Dawood and Koshio, 2020) Moreover, fermented SBM has more protein content (about 10%) than SBM with negligible change of its essential amino acids profile. In addition, fermented SBM provides probiotic characteristics, and can increase efficiency of aquafeeds by elevating trypsin and fibrinolytic enzymes activities (Dawood and Koshio, 2020).

The development of a minor biofloc in this system will be useful for reducing feed costs (Chakravarty et al., 2018; Romano, 2017; Romano and Kumar, 2017; Deepak et al., 2020).

The stages of formation of aquamimicry system are as follows (Panigrahi et al., 2019):

Step 1: Preparing the ponds.

1. Fill the cultivation pond with filtered seawater using filter bag (~200–300 μm),
2. Add probiotics (*Bacillus* sp.),
3. The sediments from the bottom of the ponds are gently dragged along the bottom with currents for

a week to allow the soil to mix with the added probiotics and also to minimize biofilm development,

4. Aquatic weeds can be removed by adding tea seed cake (20 ml L^{-1}) along with fermented rice bran or wheat bran (without husk), at a rate of 50–100 mg L^{-1} to bloom zooplankton population. Heavy aeration is essential for the proper mixing of nutrients and probiotics, and reducing the negative effects of tea seed cake.

Step 2: Using the carbon source.

1. Firstly, mix rice bran and wheat bran (without husk) with water at a ratio of 1:5 to 1:10 along with probiotics and aerate the mixture for 24 h. When the bran has been completely powdered, the entire mixture can be slowly added to the pond,
2. Secondly, add the upper layer of the mixture into the pond if crumbled. The pH of the mixed water should be 6 to 7.

Step 3: Stocking the shrimp post-larvae.

1. Shrimp post-larvae (12–15) are stocked at a density of 30 to 40 m^{-2},
2. The amount of inclusion of fermented carbon source is dependent on the turbidity of the water (30 to 40 cm), 1.0 ml L^{-1} for the extensive system and 2.0 to 4.0 ml L^{-1} for the intensive system,
3. Measure and analyze water quality parameters on a daily basis,
4. To minimize the growth of biofilms, gentle dragging should be done every 15 days after stocking,
5. The addition of probiotics should be done every month during the cultivation period in order to maintain water quality,
6. In an intensive rearing system, excess sediment must be removed to the sedimentation pond using a central drainage system. This operation should be done two hours after feeding. Sedimentation ponds must be constantly emptied. The formation of anaerobic conditions in these ponds leads to the occurrence and proliferation of pathogens, especially bacteria such as *Vibrio* sp. (Romano, 2017; Kawahigashi, 2018),
7. The sediment pond is usually 4.0 m deep in the center and 2.0 m at the edges. In these ponds, fish species such as milkfish and catfish can be stocked with low density, which not only can consume plankton and detritus, but also can provide a good source of income for farmers. Sediments from the cultivation ponds produce worms and can be consumed by aquatic animals,
8. Overflow from sedimentation ponds is directed to another pond, which serves as a biofilter that can stock species such as tilapia at low densities. Water can be overflowed into the grow-out pond from here, with little nitrogenous waste,
9. Sediment ponds should be thoroughly cleaned every three years.

Step 4: After harvesting.

After the shrimp has been harvested, the pond is completely cleaned of black soil, and residual accumulated sediment, and fermented rice is added and probiotics are prepared for the next production cycle.

Other benefits of aquamimicry aquaculture system

The protocols used to implement this system are still very diverse and depend on factors such as access to the type of carbon source, production capacity and discharge rate of the accumulated sediments (Catalani, 2020). During the cultivation season, probiotics are added to the system to help maintain water quality and increase the formation of floc floccules. Fifteen days after stocking of shrimp post-larvae in the rearing system, the central drainage of the pond floor is slowly opened to minimize biofilm formation. In addition, aquamimicry can be used for intensive culture as well. The sedimentation pond receives water from the grow-out pond through the central drainage system. Depending on the salinity of these ponds, fish like catfish or milkfish can be cultured. Fish churn up the detritus and the detritus causes oligochaete worms to grow, which fish can eat. From the sedimentation pond, it goes to the biofilter pond, where fish like tilapia can be farmed. By doing so, the amount of waste in the water is reduced, and it can be pumped back to grow-out pond. This is the general aquamimicry method for shrimp farming in Thailand.

In the Philippines, a successful aquamimicry project was completed. The project emphasized the use of natural foods in shrimp ponds. Rice bran was used as a supplementary feed in the cultivation ponds. In their study, the profitability between the conventional aquaculture and aquamimicry system was reported to be 17% and 40%, respectively.

Shrimp farming in the aquamimicry system has been successfully used by farmers in the Indian state of Andhra Pradesh. They handle pre-stocking well and are stocked at 40 PL m^{-2}, and regular aeration is provided. Supplementary feeding is provided at a low cost by using fermented rice bran (carbon source) to produce zooplankton, suitable probiotics (5.0 to 10 ml L^{-1}) are added to maintain water quality and plankton density. At regular intervals, sludge deposited on the floor of the rearing pond is removed. At the end of the cultivation period, the total production is 5.53 tons with a survival rate of 94%, which means that the cost of production per kilogram of shrimp in the aquamimicry system is approximately 65% less than in the conventional system. In addition, it is reported that the water quality and health of shrimp in the aquamimicry system is better than in the traditional shrimp farming. Shrimp produced in this system turn red during cooking, probably due to the consumption of natural foods containing pigments such as astaxanthin, amino acids and fatty acids, especially LC-PUFA, which increase their marketing value as organic shrimp (Romano and Kumar, 2017).

The challenges ahead and future perspective

New technologies are used in aquaculture, and the challenges associated with them become evident as time goes on. Aquamimicry system faces some challenges as well including:

- It is difficult to use this technology in indoor environment,
- New diseases and pathogens could occur,
- The sediment pond is relatively large (soil preparation after crop cycles) in this system.

Shrimp farming is known as an important economic activity in which the use of new technologies for its cultivation is important. Aquamimicry technique pursues the goals of sustainable aquaculture as it leads to increased production without a significant increase in the use of natural resources (water and land), it is also environmentally friendly and pursues a cost-benefit ratio to support economic and social sustainability (Santhanam et al., 2020). The use of fermented bran with probiotic in the aquamimicry system has been successful in shrimp farming because it has improved water quality and growth performance. Naturally fed shrimp in aquamimicry system may have high immunocompetence and resistance. Shrimp produced in this system are organic and do not contain any harmful chemicals or antibiotics.

Conclusion

Aquamimicry is the intersection of aquatic biology and technology that mimics the nature of aquatic eco-systems to develop living organisms for producing healthy shrimp. In some ways, aquamimicry resembles the BFT, but there are some key differences. Firstly, the amount of carbon added is reduced, and is no longer dependent on nitrogen input ratios. In addition, rather than allowing a high volume of flocs to form and suspend, in aquamimicry system sediments are removed through more intensive systems so they can be recycled by other farmed aquatic species. In an ideal environment, the water mimics the appearance and the composition of natural estuarine water with microalgae and zooplankton. Dissolved oxygen and pH fluctuations are minimized when such a balance is achieved. Additionally, there is no need for chemical manures since rice bran is a food and carbon source for zooplankton and bacteria, respectively. The water exchange is limited in this system that provides biosecurity and the presence of probiotics and FRB derived oligosaccharides provides synbiotics that induce immune responses in shrimp and provide organic marine shrimp without using therapeutics. Further research and practices are required to resolve challenges ahead of its establishment and help with progressive development of this sustainable technique in aquaculture industry.

Conflict of interests

The authors declare that they have no conflict of interest.

References

Abbaszadeh A., Mozanzadeh M.T., Qasemi A., Oujifard A., Nafisi Bahabadi M. (2022). Effects of the addition of *Calanopia elliptica*, *Artemia franciscana*, and *Brachionus rotundiformis* in a nursery biofloc system on water quality, growth, gut morphology, health indices, and transcriptional response of immune and antioxidant related genes in *Penaeus vannamei*. Aquac. Int., 30: 653–676.

Abdel-Tawwab M., Khalil R.H., Nour A.M., Elkhayat B.K., Khalifa E., Abdel-Latif H.M.R. (2022). Effects of *Bacillus subtilis*-fermented rice bran on water quality, performance, antioxidants/oxidants, and immunity biomarkers of White leg shrimp (*Litopenaeus vannamei*) reared at different salinities with zero water exchange. J. Appl. Aquac., 34: 332–357.

Albuquerque L.F.G. (2019). Desempenho zootécnico e econômico do cultivo de *Penaeus vannamei* usando o sistema aquamimicry. Tese de doutorado. Universidade Federal do Ceará (UFC). 77 pp.

Alonso-Rodriguez R., Páes-Osuna F. (2003). Nutrients, phytoplankton and harmful algal blooms in shrimp ponds: a review with special reference to the situation in the Gulf of California. Aquaculture, 219: 317–336.

Anh P.T., Kroeze C., Bush S.R., Mol A.P.J. (2010). Water pollution by intensive brackish shrimp farming in southeast Vietnam: Causes and options for control. Agric. Water Manag., 97: 872–882.

Asaduzzaman M., Wahab M.A., Verdegem M.C.J., Huque S., Salam M.A., Azim M.E. (2008). C/N ratio control and substrate addition for periphyton development jointly enhance freshwater prawn *Macrobrachium rosenbergii* production in ponds. Aquaculture, 280: 117–123.

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

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

Avnimelech Y. (2009). Biofloc Technology: A Practical Guide Book. World Aquaculture Society, Baton Rouge, Louisiana, USA. 182 pp.

Balcázar J.L., Blas I.D., Ruiz-Zarzuela I., Cunningham D., Vendrell D., Múzquiz J.L. (2006). The role of probiotics in aquaculture. Vet. Microbiol., 114: 173–186.

Bauer W.A., Prentice C.H., Tesser M.B., Wasilesky W. Jr., Poersch L.H.S. (2012). Substitution of fishmeal with microbial flocs meal and soy protein concentrations in diets for the pacific white shrimp *Litopenaeus vannamei*. Aquaculture, 342: 112–116.

Biesebeke R. (2018). Balancing microbial ecosystems within humans and animals to prevent medical conditions. J. Nutr. Food Res. Technol., 1: 40.

Biswas P.C., Sultana S., Kabiraj M., Sm S.H. (2019). Role of probiotics in aquaculture practice of Satkhira region of Bangladesh. Int. J. Fish. Aquat. Stud., 7: 174–181.

Brito L.O., Chagas A.M., Silva E.P., Soares R.B., Severi W., Gálvez A.O. (2014). Water quality, *Vibrio* density and growth of Pacific white shrimp *Litopenaeus vannamei* (Boone) in an integrated biofloc system with red seaweed *Gracilaria birdiae* (Greville). Aquac Res., 47: 940–950.

Butto L.F., Haller D. (2016). Dysbiosis in intestinal inflammation: cause or consequence. Int. J. Med. Microbiol., 306: 302–309.

Catalani K.M. (2020). Aquamimicry System: Technological alternative for intensive cultivation of marine shrimp *Litopenaeus vannamei*. A comparison with the Biofloc system (BFT). Thesis for master's degree in aquaculture. Federal University of Rio Grande. Brazil, 58P. (https://ppgaquicultura.furg.br/en/dissertations-and-theses/dissertations/184-dissertacoes-de-2020/783- dissertacao-kim-catalani-2)

Chakravarty S., Kumar S., Prakash S. (2018). Back to the basics: biomimicry in shrimp farming. Int. J. Curr. Microbiol. Appl. Sci., 7: 2172–2184.

Conceição L.E.C., Yúfera M., Makridis P., Morais S., Dinis M.T. (2010). Live feeds for early stages of fish rearing. Aquac Res., 41: 613–640.

Crab R., Defoirdt T., Bossier P., Verstraete W. (2012). Biofloc technology in aquaculture: Beneficial effects and future challenges. Aquaculture, 356–357: 351–356.

Dawood M.A., Koshio S. (2020). Application of fermentation strategy in aquafeed for sustainable aquaculture. Rev. Aquacult., 12: 987–1002.

Dawood M.A.O., Koshio S., Ishikawa M., Yokoyama S., El Basuini M.F., Hossain M.S., Nhu T.H., Dossou S., Moss A.S. (2016). Effects of dietary supplementation of *Lactobacillus rhamnosus* or/and *Lactococcus lactis* on the growth, gut microbiota and immune responses of red sea bream, *Pagrus major*. Fish Shellfish Immunol., 49: 275–285.

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

De B.C., Meena D.K., Behera B.K., Das P., Das Mohapatra P.K., Sharma A.P. (2014). Probiotics in fish and shellfish culture: Immunomodulatory and ecophysiological responses. Fish Physiol. Biochem., 50: 1–10.

De Melo F.P., Ferreira M.G.P., De Lima J.P.V., Correia E.D.S. (2015). Cultivo do camarão marinho com bioflocos sob diferentes níveis de proteína com e sem probiótico. Rev. Caatinga, 28: 202–210.

Deepak A.P., Vasava R.J., Elchelwar V.R., Tandel D.H., Vadher K.H., Shrivastava V., Prabhakar P. (2020). Aquamimicry: new and innovative approach for sustainable development of aquaculture. J. Entomol. Zool. Stud., 8: 1029–1031.

Drillet G., Jørgensen N.O., Sørensen T.F., Ramløv H., Hansen B.W. (2006). Biochemical and technical observations supporting the use of copepods as live feed organisms in marine larviculture. Aquac Res., 37: 756–772.

Drillet G., Frouël S., Sichlau M.H., Jepsen P.M., Højgaard J.K., Joarder A.K., Hansen B.W. (2011). Status and recommendations on marine copepod cultivation for use as live feed. Aquaculture, 315: 155–166.

El-Sayed A.M. (2021). Use of biofloc technology in shrimp aquaculture: a comprehensive review, with emphasis on the last decade. Rev. Aquacult., 13: 676–705.

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

Esparza-Leal H.M., Cardozo A.P., Wasielesky W. (2015). Performance of *Litopenaeus vannamei* postlarvae reared in indoor nursery tanks at high stocking density in clear-water versus biofloc system. Aquac. Eng., 68: 28–34.

FAO (2020). The state of world fisheries and aquaculture, sustainability in action. Rome, 224 pp.

Flores-Miranda C.M., Luna Gonzalez A., Cortes-Espinosa D.V., Cortes Jacinto E., Fierro-Coronado J.A., Alaves-Ruiz P., Hctor A.G.O., Ruth E.M. (2014). Bacterial fermentation of *Lemna* sp. as a potential substitute of fish meal in shrimp diets. Afr. J. Microbiol. Res., 8: 516–526.

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

Ghosh S., Sinha A., Sahu C. (2007). Effect of probiotic on reproductive performance in female live bearing ornamental fish. Aquac Res., 38: 518–526.

Gonçalves G. (2022). image of an experiment using a symbiotic system or aquamimicry at the Marine Aquaculture Station, Federal University of Rio Grande, Brazil. master's thesis. The dissertation is still being written. March, 2022.

Gonçalves-Soares D., Zanette J., Yunes J., Yepiz-Plascencia G., Bainy A.C.D. (2012). Expression and activity of glutathione *S*-transferases and catalase in the shrimp *Litopenaeus vannamei* inoculated with a toxic *Microcystis aeruginosa* strain. Mar. Environ. Res., 75: 54–61.

Hari B., Kurup B.M., Varghese J.T., Schrama J.W., Verdegem M.C.J. (2004). Effects of carbohydrate addition on production in extensive shrimp culture systems. Aquaculture, 241: 179–194.

Hong K.J., Lee C.H., Kim S.W. (2004). *Aspergillus oryzae* GB-107 fermentation improves nutritional quality of food soybeans and feed soybean meals. J. Med. Food, 7: 430–435.

Hou D., Huang Z., Zeng S., Liu J., Weng S., He J. (2018). Comparative analysis of the bacterial community compositions of the shrimp intestine, surrounding water and sediment. J. Appl. Microbiol., 125: 792–799.

Huynhtg Y.L., Shiu T.P., Nguyen Q.P., Truong Q., Chen J., Liu C. (2017). Current applications, selection, and possible mechanisms of actions of synbiotics in improving the growth and health status in aquaculture: a review. Fish Shellfish Immunol., 64: 367–382.

Iber B.T., Kasan N.A. (2021). Recent advances in shrimp aquaculture wastewater management. Heliyon, 7: e08283.

Jahangiri L., Esteban M.A. (2018). Administration of probiotics in the water in finfish aquaculture systems: A review. Fishes, 3: 33.

Jannathulla R., Dayal J.S., Vasanthakumar D., Ambasankar K., Muralidhar M. (2017). Effect of fermentation methods on amino acids, fiber fractions and anti-nutritional factors in different plant protein sources and essential amino acid index for *Penaeus vannamei* Boone, 1931. Indian J. Fish., 64: 40–47.

Jannathulla R., Dayal J.S., Vasanthakumar D., Ambasankar K., Panigrahi A., Muralidhar M. (2019). Apparent digestibility coefficients of fungal fermented plant proteins in two different penaeid shrimps – A comparative study. Aquac. Res., 50: 1491–1500.

Jayaprakashvel M., Subramani R. (2019). Implications of quorum sensing and quorum quenching in aquaculture health management. In: Implication of quorum sensing and biofilm formation in medicine, Agriculture and Food Industry. Springer, Singapore, pp. 299–312.

Karlsen Ø., Van Der Meeren T., Rønnestad I., Mangor Jensen A., Galloway T.F., Kjørsvik E., Hamre K. (2015). Copepods enhance nutritional status, growth and development in Atlantic cod (*Gadus morhua* L.) larvae – Can we identify the underlying factors? Peer J., 3: e902–e902.

Kawahigashi D. (2018). Resultados de producción utilizando sistemas simbióticos. Anais do Aqua Expo El Oro 2018.

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

Khanjani M.H., Sharifinia M. (2021). Production of Nile tilapia *Oreochromis niloticus* reared in a limited water exchange system: The effect of different light levels. Aquaculture, 542: 736912.

Khanjani M.H., Sharifinia M. (2022). Biofloc technology with addition molasses as carbon sources applied to *Litopenaeus vannamei* juvenile production under the effects of different C/N ratios. Aquac. Int., 30: 383–397.

Khanjani M.H., Sharifinia M., Hajirezaee S. (2020). Effects of different salinity levels on water quality, growth performance and body composition of Pacific white shrimp (*Litopenaeus vannamei* Boone, 1931) cultured in a zero water exchange heterotrophic system. Ann. Anim. Sci., 20: 1471–1486.

Khanjani M.H., Alizadeh M., Sharifinia M. (2021 a). Effects of different carbon sources on water quality, biofloc quality, and growth performance of Nile tilapia (*Oreochromis niloticus*) fingerlings in a heterotrophic culture system. Aquac. Int., 29: 307–321.

Khanjani M.H., Alizadeh M., Mohammadi M., Sarsangi Aliabad H. (2021 b). Biofloc system applied to Nile tilapia (*Oreochromis niloticus*) farming using different carbon sources: growth performance, carcass analysis, digestive and hepatic enzyme activity. Iran. J. Fish. Sci., 20: 490– 513.

Khanjani M.H., Alizadeh M., Mohammadi M., Sarsangi Aliabad H. (2021 c). The effect of adding molasses in different times on performance of Nile tilapia (*Oreochromis niloticus*) raised in a low-salinity biofloc system. Ann. Anim. Sci., 21: 1435–1454.

Khanjani M.H., Sharifinia M., Hajirezaee S. (2022 a). Recent progress towards the application of biofloc technology for tilapia farming. Aquaculture, 552: 738021.

Khanjani M.H., Eslami J., Ghaedi G., Sourinejad I. (2022 b). The effects of different stocking densities on nursery performance of banana shrimp (*Fenneropenaeus merguiensis*) reared under biofloc condition. Ann. Anim. Sci., DOI: 10.2478/aoas-2022-0027.

Kim S., Pang Z., Seo H., Cho Y.R., Samocha T., Jang I.K. (2014). Effect of biofloc on growth and immune activity of Pacific white shrimp, *Litopenaeus vannamei* post larvae. Aquac Res., 45: 362–371.

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

Lara-Flores M. (2011). The use of probiotic in aquaculture: an overview. Int. Res. J. Microbiol., 2: 471–478.

Leu M.Y., Sune Y.H., Meng P.J. (2015). First results of larval rearing and development of the bluestriped angelfish *Chaetodontoplus septentrionalis* (Temminck and Schlegel) from hatching through juvenile stage with notes on its potential for aquaculture. Aquac Res., 46: 1087–1100.

Liñan-Vidriales M.A., Peña-Rodríguez A., Tovar- Ramírez D., Elizondo-González R., Diana R. Barajas-Sandoval D.R., Ponce-Gracía E.I., Rodríguez-Jaramillo C., Balcázar J.L., Quiroz-Guzmán E. (2021). Effect of rice bran fermented with *Bacillus* and *Lysinibacillus* species on dynamic microbial activity of Pacific white shrimp (*Penaeus vannamei*). Aquaculture, 531: 735958.

Liu K.F., Chiu C.H., Shiu Y.L., Cheng W., Liu C.H. (2010). Effects of the probiotic, *Bacillus subtilis* E20, on the survival, development, stress tolerance, and immune status of white shrimp, *Litopenaeus vannamei* larvae. Fish Shellfish Immunol., 28: 837–844.

Martinez-Cordova L.R., Campana-Torres A., Martinez-Porchas M. (2011). Effect of supplying four copepod densities (*Acartia* sp. and *Calanus pacificus*) on the productive response of *Litopenaeus vannamei* pregrown intensively at microcosm level. Ciencias Marinas, 37: 415–423.

Martínez Cruz P., Ibáñez A.L., Monroy Hermosillo O.A., Ramírez Saad H.C. (2012). Use of probiotics in aquaculture. ISRN Microbial., ID 916845, 13 pp.

Merrifield D.L., Dimitroglou A., Foey A., Davies S.J., Baker R.T., Bøgwald J., Castex M., Ringø E. (2010). The current status and future focus of probiotic and prebiotic applications for salmonids. Aquaculture, 302: 1–18.

Mulyasari Kurniawati F., Setiawati M. (2013). Cassava digestibility through chemical and biological treatment as feed for tilapia. Indones. Aquac. J., 12: 178−185.

Nathanailides C., Kolygas M., Choremi K., Mavraganis T., Gouva E., Vidalis K., Athanassopoulou F. (2021). Probiotics have the potential to significantly mitigate the environmental impact of freshwater fish farms. Fishes, 6: 76.

Nisar U., Peng D., Mu Y., Sun Y. (2022). A solution for sustainable utilization of aquaculture waste: A comprehensive review of biofloc technology and aquamimicry. Front. Nutr., https://doi.org/10.3389/fnut.2021.791738.

Panigrahi A., Otta S.K., Kumaraguru Vasagam K.P., Shyne Anand P.S., Biju I.F., Aravind R. (2019). Training manual on Biofloc technology for nursery and grow out aquaculture, CIBA TM series, 15: 172.

Qiu X., Davis D.A. (2018). Evaluation of dried fermented biomass as a feed ingredient in plant-based practical diets for juvenile Pacific white shrimp *Litopenaeus vannamei.* Aquac. Nutr., 24: 383–391.

Radhakrishnan D.K., Ali I.A., Schmidt B.V., John E.M., Sivanpillai S., Vasunambesan S.T. (2019). Improvement of nutritional quality of live feed for aquaculture: An overview. Aquac Res., 51: 1–17.

Razak D.L., Rashid N.Y., Jamaluddin A., Sharifudin S.A., Kahar A., Long K. (2017). Cosmeceutical potentials and bioactive compounds of rice bran fermented with single and mix culture of *Aspergillus oryzae* and *Rhizopus oryzae.* J. Saudi Soc. Agric. Sci., 16: 127–134.

Ren Z., Li A., Jiang J., Zhou L., Yu Z., Lu H., Xie H., Chen X., Shao L., Zhang R., Xu S., Zhang H., Cui G., Chen X., Sun R., Wen H., Lerut J.P., Kan Q., Li L., Zheng S. (2018). Gut microbiome analysis as a tool towards targeted non-invasive biomarkers for early hepatocellular carcinoma. Gut, 68: 1014–1023.

Romano N. (2017). Aqamimicry: A revolutionary concept for shrimp farming. The Global Aquaculture Advocate, pp. 1–6.

Romano N., Kumar V. (2017). Vegetarian shrimp: pellet-free shrimp farming. World Aquaculture, 12: 36–39.

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

Santhanam P., Manickam N., Perumal P. (2020). Biofloc-copefloc: A novel technology towards sustained aquaculture. J. Indian Soc. Coast. Agric. Res., 38: 43–50.

Satoh N., Takaya Y., Takeuchi T. (2009). The effect of docosahexaenoic and eicosapentaenoic acids in live food on the development of abnormal morphology in hatchery-reared brown sole *Pseudopleuronectes herzensteini*. Fish. Sci., 75: 1001–1006.

Shi C., He J., Yu J., Yu B., Huang Z., Mao X., Zheng P., Chen D. (2015). Solid state fermentation of rapeseed cake with *Aspergillus niger* for degrading glucosinolates and upgrading nutritional value. J. Anim. Sci. Biotechnol., 6: 4618.

Suprayudi A.M., Edriani G., Ekasari J. (2012). Evaluation of fermented product quality of various byproduct of local agroindustry: its influence on digestibility and performance of juvenile growth of common carp. Indones. Aquacu. J., 11: 1–10.

Taher S., Romano N., Arshad A., Ebrahimi M., Teh J.C., Ng W.K., Kumar V. (2017). Assessing the feasibility of dietary soybean meal replacement to the swimming crab, *Portunus pelagicus*, juveniles. Aquaculture, 469: 88–94.

Teixeira P. (2011). Fito plâncton e Protozooplâncton em viveiros de cultivo de camarão. Dissertação de mestrado. Oceanografia biológica. Rio Grande, RS, 54 pp.

Van Nguyen N., Hoang L., Van Khanh T., Duy Hai P., Hung L.T. (2018). Utilization of fermented soybean meal for fishmeal substitution in diets of Pacific white shrimp (*Litopenaeus vannamei*). Aquac. Nutr., 24: 1092–1100.

Vidal J.M.A., Pessôa M.N.D.C., Santos F.L.D., Mendes P.D.P., Mendes M.S. (2018). Probiotic potential of *Bacillus cereus* against *Vibrio* spp. in post-larvae shrimps. Rev. Caatinga, 31: 495–503.

Wilcox J.A., Tracy P.L., Marcus N.H. (2006). Improving live feeds: Effect of a mixed diet of copepod nauplii (*Acartia tonsa*) and rotifers on the survival and growth of first feeding larvae of the southern flounder, *Paralichthys lethostigma*. J. World Aquac. Soc., 37: 113–120.

Xiong J., Dai W., Qi Q., Zhu J., Yang W., Li C. (2018). Response of host-bacterial colonization in shrimp to developmental stage, environment and disease. Microb. Ecol., 27: 3686–3699.

Xiong J., Xuan L., Yu W., Zhu J., Qiu Q., Chen J. (2019). Spatiotemporal successions of shrimp gut microbial colonization: high consistency despite distinct species pool. Environ. Microbiol., 21: 1383–1394.

Xiong J., Li X., Yan M., Lu J., Chen J. (2020). Comparable ecological processes govern the temporal succession of gut bacteria and micro eukaryotes as shrimp aged. Microb. Ecol., 80: 935–945.

Zeng S., Khoruamkid S., Kongpakdee W., Wei D., Yu L., Wang H., Deng Z., Weng S., Huang Z., He J., Satapornvanit K. (2020). Dissimilarity of microbial diversity of pond water, shrimp intestine and sediment in aquamimicry system. AMB Express, 10: 1–11.

Zubaidah E., Nurcholis M., Wulan S.N., Kusuma A. (2012). Comparative study on synbiotic effect of fermented rice bran by probiotic lactic acid bacteria *Lactobacillus casei* and newly isolated *Lactobacillus plantarum* B2 in Wistar rats. APCBEE Procedia, 2: 170–177.

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