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REVIEW

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# Aquamimicry (Copefloc technology): an innovative approach for sustainable organic farming with special reference to shrimp aquaculture

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**Abstract**

With the rising demand for fish worldwide, aquaculture's contribution to the global food supply is crucial. To conserve natural resources by relying less on water supplies and minimizing land use, different cutting-edge technologies have been developed. These innovative, cutting-edge technologies should emphasize on environmental conservation and eco-safety by imparting environmental benefits, biosecurity safeguards, environmentally sound activities, mitigating substantial environmental concerns, and transmission of diseases. Shrimp farming has historically produced the highest profits in the aquaculture industry. The sector holds promise for foreign earnings and has boomed worldwide. Aquamimicry technology is one of the many novel technologies that have shown promising results in achieving long-term sustainability in the thriving shrimp farming sector. This novel method simulates a natural environment in controlled conditions by harnessing heterotrophic microorganisms thereby offering benefits for low-oxygen-intensive farming practices. Maintaining a specific C:N ratio in this system with the help of probiotics allows heterotrophic bacteria to make use of the nitrogenous metabolites released by food and waste matter, hence facilitating in preserving water quality, and providing protein-rich live feed i.e., copepods. As we all are well aware that feed cost makes up more than half of the entire cost of production in most culture system. Therefore, this innovation not only aids in maintaining water quality and health of the organism but also significantly reduces the reliance on supplementary feed, rendering it a profitable long-term strategy for aquaculture. Although the concept has been around for a while, aquaculture farmers are yet to adopt this method as information is sparse. The current review focuses on elucidating the underlying process, existing knowledge, and future prospects of aquamimicry technology, also known as Copefloc technology, to accelerate the advancements in shrimp farming industry.

**Keywords** Aquamimicry, Copefloc technology, Copepod, Fermentation, Probiotics, Sustainable aquaculture, Shrimp

## Introduction

Aquaculture is indispensable to the world's food supply due to the surging global demand for fish. Currently, over a billion people obtain the majority of their recommended daily intake of animal protein solely from fish [79]. Fish farming is a key economic activity in many countries since it provides people access to food and nutrition besides serving as a means of livelihood. It

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has been assessed that the aquaculture sector employs around 22.10 million people worldwide. In 2022, it was estimated that the worldwide population consumed 20.70 kg of fish per person, while global fisheries and aquaculture production was 185.40 million tones [29]. Alongside these nutritional benefits and employment opportunities, aquaculture offers a sustainable alternative to other farmed proteins, with the added advantage of highest feed conversion efficiency. Aquaculture can be considered sustainable if it improves the health of the population in an environmentally friendly, socially responsible, and animal-friendly manner [15]. Shrimp aquaculture has been consistently yielding the highest revenues within the aquaculture sector. Despite its tremendous production, the expansion of the culture system, notably in shrimp farming, has generated a massive amount of waste. The high stocking density and deteriorated water quality in this intensified system have been the triggering stress factors leading to the outbreak of a number of diseases in the shrimp and prawn industries. To cope up with these issues in the aquaculture industry, a number of health management measures have been put in place. Such measures include greater biosecurity and the procurement of pathogen-free animals, as well as employment of chemicals and medicines as a last resort [79]. However, even with such practices, it is often impractical to eliminate all the pathogens from the culture system. In addition, certain activities, like the indiscriminate use of antibiotics and chemotherapeutics, have aroused public health concerns. This hassle was further intensified by the irresponsible discharge of water contaminated with various chemicals and food waste into the surrounding water and land. Similar issues were prevalent in Asian aquaculture as well, speciifcally in the shrimp farming sector. Furthermore, apart from the risks associated with diseases and environmental concerns, there are numerous challenges related to feed cost and availability, especially regarding fish meal and fish oil [18], as well as the high input practices to consolidate the intensified shrimp industries, which have escalated the production cost and market volatility [28].

Considering all these adversities, it is the need of the hour to develop a technology that would provide sustainable production while conserving the environment hand in hand. There are several cutting-edge technologies that can be applied in areas with poor agricultural and soil conditions that concurrently contribute to export revenues. These technologies ought to effectively uphold the conservation of natural resources, thus mitigating disease transmission risks, while exemplifying biosecurity, economic viability, and ecological integrity in their implementation. Herewith, aquamimicry technology has been appraised for being an environment-friendly technique that does not rely on toxic chemicals while maintaining a consistent output with minimal input cost. This concept probably first appeared in Thailand in the 1990s [68] and presents a promising avenue of ensuring long-term sustainability in culturing shrimp through the utilization of a carbon source and enhancing the water quality. This novel method mimics a natural ecosystem under controlled conditions by using heterotrophic bacteria. It involves cultivating blooms of zooplankton, especially copepods, to offer as a supplemental live feed for shrimp and to stimulate the production of beneficial bacteria thereby aiding in water quality management [64]. In this system, carbon supply (rice bran) and probiotics promote the growth of phytoplankton and zooplankton blooms and assists in stabilizing the ecosystem's water quality and offers additional nourishment for farmed fish and shrimp [82]. Both biofloc technology (BFT) and aquamimicry technology are innovative approaches being employed in aquaculture to improve water quality, enhance productivity, and promote sustainability. BFT entails the cultivation of microbial flocs (heterotrophic bacteria) within the aquaculture system, thereby enhancing the absorption of inorganic nitrogen through adjustment of the carbon to nitrogen (C:N) ratio of 15:1 and maintains water quality, recycle nutrients, and supplement nutrient for cultured organisms. Conversely, aquamimicry technology strives to emulate natural aquatic ecosystems and processes within aquaculture systems to bolster productivity and sustainability. Several limitations of BFT were subdued with the adoption of aquamimicry.

## Concept of aquamimicry

Amid the disease epidemics of the 1990s, this approach was conceptualized in Thailand. Although certain ponds were found to be in close proximity to diseased ponds, it was also observed that shrimp in other ponds were growing productively and disease-free despite the lack of formulated aquafeeds provided by their farmers. The success of these ponds has been attributed in part to the exclusive use of rice bran. Hence, a procedure gradually evolved over time. Aquamimicry was initially employed by two shrimp farmers of Thailand in 2013. Their concept proposes that shrimp cultivation can adopt a more ecologically friendly approach by simulating the aquaculture system to emulate natural aquatic conditions. It is a low-cost strategy based on mimicking the natural aquatic conditions by nourishing shrimps with live food such as zooplanktons and deploying beneficial microorganisms to improve water quality [59, 68]. Figure 1 illustrates the general layout of a farm in Thailand that utilizes the aquamimicry concept for intensive culturing of shrimp.

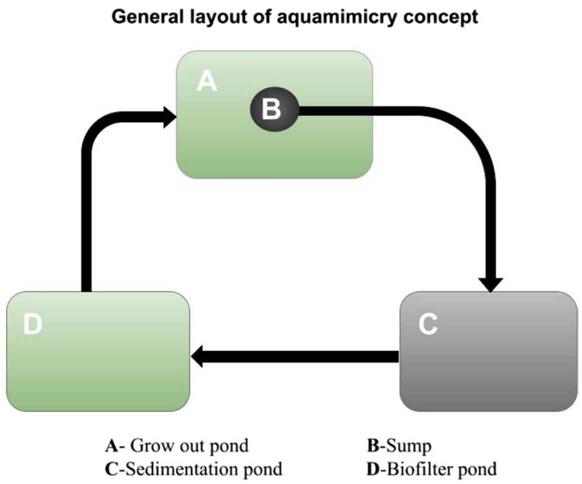

**Fig. 1** General layout of aquamimicry concept

The system includes, (**A**) a grow-out pond equipped with eight long-arm paddlewheels to promote water circulation, (**B**) a central sump where solids and waste are concentrated, (**C**) asedimentation pond (4 m deep at the center) suitable for culturing milkfish or catfish, and a (**D**) biofilter pond for culturing tilapia. The water returns to the growout pond with relatively low levels of nitrogenous waste. Moreover, the plastic liner is intended to slow the flow of water and extend its retention period [69]

To impart efficient nutrition to farmed shrimp as well as to maintain water quality, aquamimicry attempts to recreate the circumstances of a natural estuary by growing blooms of zooplankton (mainly copepods) and other beneficial bacteria. Zooplankton is the natural diet of many larval stages of aquaculture commodities, and its cultivationis considered the second level of live food production in aquaculture systems. Ensuring a consistent supply of live food rich in nutrients is paramount for the success of both hatchery operations and production [60]. In this context, to boost the growth of zooplankton (copepods), a variety of probiotics (including *Bacillus* sp.) and carbon sources (such as rice bran and wheat bran) are utilized. The incorporated probiotics will ferment the carbon sources during its growth. The fermented substrate along with the associated probiotics will be harnessed as a feed for phytoplankton and zooplankton to boost their growth, which in turn will be fed upon by the farmed shrimp. The utilization of carbon sources such as soybean meal, rice bran, and wheat bran is pivotal for success, alongside the application of probiotics to augment zooplankton blooms. Live feed, typically consisting of copepods enriched with taurine (a free amino fatty acid) and pigments, is employed. The addition of LC-PUFA (long-chain polyunsaturated fatty acids), minerals, and trace elements can improve feed efficiency and immunological competence [12, 14, 19]. Nitrogen metabolites are recycled and the water quality is improved due to the addition of probiotics and fermented carbon sources [23, 59, 60]. This technique generates a symbiotic link between fermented carbon sources like oligosaccharides and probiotics (*Bacillus* sp.), thereby, reducing the reliance on the use of medications and offers a sustainable aquaculture practices [72, 85]. Upon achieving this equilibrium, fluctuations in pH and dissolved oxygen levels are minimized, obviating the need for antibiotics or chemicals. Rice bran, utilized by zooplankton and bacteria as a prebiotic, facilitates the formation of "synbiotics," which are dietary supplements or additives that synergistically combine prebiotics and probiotics [60, 69].

By using carbon sources such as rice bran and wheat, as well as probiotics, this technology imitates natural pond conditions by creating beneficial phyto- and zooplankton blooms as supplemental nourishment for farmed shrimp while simultaneously facilitating the maintenance of water quality through the presence of beneficial bacteria. Aquamimicry works on a similar premise to biofloc technology; however, several differences exist between them. This technology minimizes the requirement for carbon sources, particularly rice bran, as its input is not contingent on nitrogen ratio. It involves the routine removal of sediment from suspended bioflocs, which serves various purposes such as manure, animal feed and so on. This approach offers the added advantage of greater sustainability compared to traditional methods as shrimp develop high immunity and health, showed improved feed conversion ratios, involved minimal water exchange, and reduced disease outbreaks. Consequently, the overall nutrition of farmed shrimp is improved, animal stress is minimized and conducive environments for harmful organisms are curbed [12, 14, 23].

## Protocol of shrimp farming using aquamimicry (copefloc technology)

The shrimp farming system employing the latest aquamimicry technique, also known as copefloc technology, is delineated through four distinct steps, elaborated upon in detail. The steps include pond preparation, which is done prior to stocking, where fermented rice bran (FRB) is used, carbon source application, and post-larvae (PL) stocking, followed by post-harvest maintenance. Panigrahi and Biju [61] outlined the four stages of the aquamimicry system, as depicted in Fig. 2.

Step I: Preparation of pond

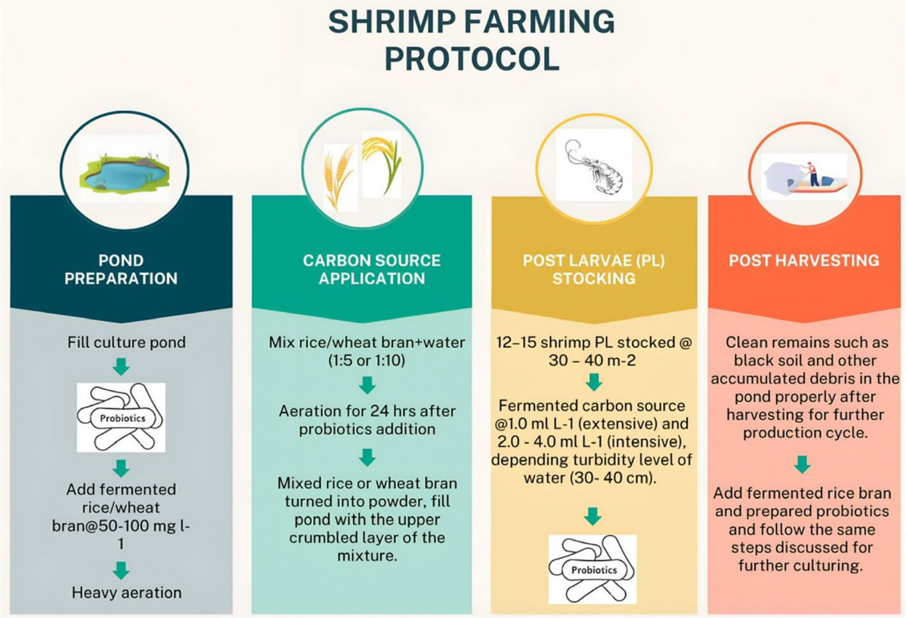

**Fig. 2** Aquamimicry Shrimp Farming Protocol

a) Pump the filtered (sea) water into the culture pond using filter bags (200–300 m).
b) Supplement with probiotics like *Bacillus* sp.
c) Drag the sediments from the pond bottom gently.
d) Continue this dragging for a week to prevent the development of biofilm and to enable the combination of soil with the probiotics.
e) Fermented rice bran or wheat bran (huskless) is supplied at a rate of 50–100 mg $L^{-1}$ to enhance the zooplankton bloom and to remove aquatic weeds (20 ml $L^{-1}$).The process for preparing fermented rice bran is discussed below.
f) Heavy aeration is provided to properly mix the nutrients and probiotics and to mitigate the harmful effects of tea seed cake.

Step II: Carbon source application

a) Huskless rice or wheat bran are mixed with water at a ratio of 1:5 to 1:10.
b) Aeration is given with the addition of probiotics. Allow the mixture to aerate for 24 h.
c) Once this mixed rice or wheat bran turned into powder, fill the pond with the upper crumbled layer of the mixture.
Note that the pH of the mixture is always maintained around 6.

Step III: Post larvae (PL) stocking

a) 12–15 shrimp post-larvae are stocked at 30 – 40 $m^{-2}$ culture pond.
b) The fermented carbon source is then applied, at the rate of 1.0 ml $L^{-1}$ (extensive) and 2.0—4.0 ml $L^{-1}$ (intensive), depending on the turbidity level of water (30- 40 cm).
c) Drag the sediments every two weeks after stocking from the pond bottom gently.
d) Add probiotics on a monthly basis to minimize biofilm formation and sustain water quality throughout the cultivation period, typically @1–5 ml of probiotic solution per liter of water/ 1–10 g of probiotic powder per cubic meter of water, considering the specific probiotic, water conditions, and shrimp density.
e) Remove extra silt intensively from the sedimentation pond through the central drainage system which is 2.0 m deep at the sides and 4.0 m deep in the middle.
Note that there should be periodic (daily) monitoring of water quality parameters in all the culture units. Drainage and removal of silt should be done two hours post-feeding since the development of anaerobic conditions can stimulate the development and spread of pathogenic microorganisms, particularly *Vibrio* sp. [41, 68]. In order to consume excess growth of plankton and detritus naturally, milkfish and catfish can be stocked at a lower density, which can be an additional source of income for the farmers.

Step IV: Post harvesting

a) Clean the remains such as black soil and other accumulated debris in the pond properly after harvesting for further production cycle.
b) Then, add fermented rice bran and prepared probiotics and follow the same steps discussed for further culturing.
Note that proper care should be taken with maintenance to prevent the development of unwanted diseases or pathogens.

### Technique employed in preparing fermented rice bran

In aquamimicry shrimp farming system, rice bran or wheat bran (huskless) are used as an excellent source of carbon [62]. To act as a carbon source, fermented rice bran is prepared by combining powdered rice bran, probiotics, and hydrolyzing enzymes mixed with water and keeping it for one day [4]. Here, fermented rice bran is used at the rate of 500 to 1000 kg ha$^{-1}$, serving both as a prebiotic and imparting a synbiotic effect when combined with probiotic microorganisms. Copepods proliferate one week after the application in the cultivation pond at the optimal concentration prior to the PL stocking, then the PLs are stocked at a density of 10 to 20 organisms per m$^{-2}$. To support zooplankton blooms and the development of floc floccules (typically 1.0 ml L$^{-1}$) during the rearing period, ponds are routinely supplied with fermented rice bran [59]. The suitable inclusion of fermented rice bran is also determined by the turbidity of the water in the system. The inclusion of fermented rice bran subsists the fermented soybean meal, moreover, it delivers lower molecular weight peptides, boosting micronutrient bioavailability, and low anti-nutritional factor (ANF).

Fermented soybean was also employed as an alternative to fermented rice bran, hence, aiding in enhancing the digestibility of cultured species and augmenting their nutritional value [22, 34]. Additionally, it stimulates essential alterations in the amino acid profile, elevates protein content by approximately 10%, imparts probiotic qualities, and increases the activity of trypsin and fibrinolytic enzymes in aquafeeds, thereby heightening their efficacy [22, 60]. This fermentation process holds great importance as it enhances nutrient bioavailability and digestion rate [2, 76]. It improves the nutritional value of alternative protein sources while concurrently reducing the anti-nutritional factors when incorporated into feed formulation [22].The high fiber content in grains and cereals leads to poor digestibility and limited growth, and ANF reduces levels of essential amino acids such as methionine, lysine, and tryptophan. However, these antinutritional factors and toxic chemicals can be alleviated during the anaerobic fermentation by the probiotic bacteria via the hydrolytic activities of the enzymes produced thereby increasing the nutritional value of the plant proteins and grains [37, 65, 74]. During the fermentation process, carbohydrates are converted into microbial proteins, consequently augmenting the content of proteins, vitamins, minerals, and amino acids in fermented foods, while simultaneously reducing the levels of fiber and ANF [37, 65]. It is preferably chosen as it offers better nutritional value due to its high protein content and digestibility while decreasing ANF, fat, ash, and phytic acid [5, 30].

Fermented rice bran is more preferable due to its varied usage, importance, and value. According to Deepak et al. [23], agricultural wastes like rice bran, cereals, etc. are commonly utilized as sources of carbon and energy in aquaculture feeds. Rice bran, despite having a lot of nutrients, is widely available at reasonable prices. The significance of rice bran lies in its ability to improve feed digestibility in shrimp [50], and fermented cereal meal is more nutritious and gets digested faster than other nonfermented cereals, making it a viable partial substitute for nutritional fishmeal in shrimp feed formulations [38]. Further study on the use of rice bran indicated that the biochemical compositions after fermentation offers high nutritive value, *viz.*, protein of 16.79%, fats of 14.92%, ash of 17.36%, and total carbohydrates of 50.94%, respectively [5]. The process of fermentation using rice bran as a medium is a rapid process, inexpensive, and posses low-risk besides increasing the availability of nutrients [70]. According to Zubaidah et al. [86], probiotic bacteria in animals' guts make use of the fiber content of rice bran to obtain short-chain fatty acids. Furthermore, the study conducted by Abdel-Tawwab et al. [3] revealed that the system relying on fermented rice bran substantially diminishes the presence of harmful bacteria such as *Vibrio* sp. while it elevates the levels of beneficial bacteria such as *Bacillus* sp. There has been an observed increase in the growth of *Litopenaeus vannamei*, resulting in high-productivity. Moreover, probiotic-rich fermented rice bran like *LysiniBacillus* sp. and *Bacillus* sp. improved *L. vannamei* survival and growth rates [52].

### Application of probiotics

Probiotics are live beneficial bacteria that alter the intestinal flora of their hosts, thereby improving the growth and health of cultured fish and the system itself when introduced through a food or water source [11, 21, 57, 75, 81]. The significance of its application is that it helps to preserve the gut microbiota and also elevate plant nutrient content through fermentation. It also disrupts the bacteria's quorum-sensing mechanism, which controls biofilm formation and virulence factors [13, 39]. During the fermentation process, enzymes were released that decreased the pH of the stomach and lessened the activities and development of hazardous substances [55]. The use of probiotics, as stated by Lara-Flores [50], facilitates the development of beneficial microorganisms in the gut by inhibiting the growth of harmful bacteria. *Bacillus* sp., a spore-forming gram-negative bacteria, is a promising probiotic for use in aquaculture since it can be stored at room temperature without affecting its biological function. Furthermore, other beneficial probiotic bacteria were also developed, such as *B. subtili*, which produces essential vitamins, i.e., vitamin B1 and vitamin B12 [31]. Moreover, the use of probiotics helps to enhance nutritional efficacy and feed conversion ratio, resulting in cutting down on the expenses associated with feeds [81]. In aquamimicry system, probiotics play a significant role by providing synbiotic effects with fermented carbon source derivatives, limiting the spread of pathogenic harmful bacteria via the mechanism of quorum sensing, boosting shrimp immunity, assisting in situ water bioremediation, and improving post-larval survival rates. Probiotics are considered environmentally friendly and a biodegradable supplement for a wider range of organisms and a variety of activities. Moreover, it also regulates hazardous gases and increases the amount of oxygen that can be dissolved in situ due to its different factors, including biological and chemical oxygen needs and total suspended solids [58]. The use of probiotics in aquaculture system is presumed to be a good substitute for antibiotics and is now being frequently used in modern aquaculture systems [56, 80] for prevention of infectious diseases as well as enhancing water quality [36, 53] .

### Use of copepods as live foods and different microbial populations in the aquamimicry system

Aquamimicryis a natural food-based technique that utilize copepods specifically as livefeed for the stocked shrimp [23, 72]. The maturity of the system is indicated by the displacement of other zooplankton species with copepods, which emerge as one of the dominant species [17]. Because of their short lifespan and small size, they are commonly utilized as a food source for many species, a source of energy, and a recycler of nutrients in the marine food chain [17, 66]. By the second week, they typically establish control over the system [71]. Their adoption in the aquaculture industry is expanding due to their significant biochemical composition, particularly in aiding survival and growth at different life stages of farmed shrimp, *viz.*,eggs, nauplii, pre-adults, and adults [1, 17, 24, 25]. The utilization of copepods holds considerable importance and offers manifold benefits, as they exhibit superior nutritional qualities compared to rotifers and brine shrimp. This is attributed to their inherently high levels of LC-PUFAs and other essential fatty acids, such as eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and arachidonic acid (ARA), which play crucial roles in their development and growth [73, 83]. According to studies by Karlsen et al. [40] and Taher et al. [77], copepods are rich in carotenoids, free amino acids, peptides like taurine, minerals including selenium, iodine, copper, and manganese, as well as several vitamins. Copepods with nauplii size ranging between 50 and 60 mm exhibit narrower mouth apertures, rendering them particularly well-suited for feeding larval stages of various aquaculture species. Due to their relative sizes, copepodites and adult stages have been employed to feed higher larval stages effectively [51]. According to Martinez-Cordova et al. [54], the inclusion of copepods (*Calanus pacificus* and *Acartia* sp.) during the nursery rearing system significantly improved the survival and growth rate of *L. vannamei*. According to Abbaszadeh et al. [1], the addition of copepods, *Calanopia elliptica*, at 0.2 per ml improved shrimp growth, immune system, and feed conversion efficiency.

Other than copepods, phytoplankton and zooplankton produced in the system contributed to their feed. The generation of diverse phytoplankton and zooplankton variants of varying qualities is influenced by a range of environmental factors, including temperature, light exposure, salinity, and the availability of nutrients [6]. Catalani [16] in his study observed the colonies of microorganisms and different planktons in two systems, *viz.*, BFT and aquamimicry, while rearing the Pacific white shrimp, *L. vannamai*, for 120 days. He discovered that the aquamimicry system had more cyanobacteria and flagellates as compared to that of the BFT, but fewer chlorophytes and diatoms were observed. During the beginning of the culture period, the concentration of rotifers and ciliates was higher than that of BFT. However, flagellates eventually took control and emerged as the dominant group. The study also disclosed that cyanobacteria experienced a bloom during the mid-stage of the system's development [16]. Toxins produced by cyanobacteria, as reported by Gonçalves-Soares et al. [32], may have a negative impact on shrimp physiology, leading to high mortality rates. The increase in nutrients like phosphate causes a rise in the concentration of flagellum density in the rearing system. According to Teixeira [78], flagellum densities increase in systems even without the use of carbon sources. In aquamimicry system, the inclusion of fermented carbon sources and probiotics aids in the equilibrium of zooplankton and phytoplankton, thus creating the ideal habitat for optimal growth and well-being. Infection of the species cultured may be considerably reduced by controlling the microbial populations in the aquaculture system. Some of the notable infections, such as viral hemorrhagic septicemia (VHS), infectious hematopoietic necrosis (IHN), white spot syndrome virus (WSSV), spring viremia of carp (SVC), bacterial infections like *Aeromonas hydrophila*, parasitic infections, bacterial coldwater disease (BCWD), epizootic ulcerative syndrome (EUS), and parasitic amoebic gill disease (AGD), can be mitigated or prevented. Infections can be reduced by imitating the natural microbial community, which thrives in their digestive tract and surrounding environment, and the diversity of gut microbes serves as an accurate indicator of host health [67]. According to research by Xiong et al. [84], the shrimp gut microbiota is strongly connected to the shrimp's life stage and moderately influenced by the water environment. Zeng et al. [85] analyzed the correlation between shrimp gut contents like microbiota, sediments, and water, as well as the nature of the gut microbiota and the microbial communities in the environment. They discovered that among the variety of microorganisms in the digestive tract, as well as those in the water and sediment, Proteobacteria (32%), was the most common, followed by Bacteroides (11%), Planctomycetes (8%), Chloroflexi (6%), Actinobacteria (5%), Patescibacteria (9%), Firmicutes (7%), Errucomicrobia (4%), Cyanobacteria (3%), Acidobacteria (2%), and other different microorganisms (13%). In this system, *Vibrio* sp. and *B. stearothermophilus* have been found to dominate the shrimp digestive tract, while opportunistic pathogens like *Aeromonas*, *Phascolarcto bacterium*, and Photobacterium were rarely observed. The microbial diversity is influenced by the rearing method, and this could serve as an indicator on farms. These findings offer insight into the significance of microbial communities in the aquamimicry system and have the potential to increase farm profitability..

### A case study on aquamimicy system in Andhra Pradesh, India

In a study conducted in Vijayawada, Andhra Pradesh, aquaculture-based shrimp farming was implemented by farmer Ganesh Mokkapati, who adopted a stocking density of 40 post-larvae per square meter ($PLm^{-2}$). A brief description of how he implemented the system is being discussed. He used a plus-shape, long-armed aerator to maintain the pond's dissolved oxygen level. Soil pH, ammonia (N), and nitrate (N) levels were assessed prior to the production cycle and treated with probiotics. To ensure pH stability throughout the culture period, the pond water was treated with fermented rice bran (5–10 ppm) and probiotics, resulting in a distinctive golden brown hue of the water. It not only aids in maintaining the pH stable at regular intervals, but it also increases plankton concentration. Sludge removal on time keeps the pond bottom clean and prevents the system from releasing toxic gases such as ammonia and nitrite. The major cost in the production system is the reliance on fish meal hence, alternative natural feed was used to reduce production costs. Fermented soybeans with fish sauce and commercial pellets were used, thus lowering production costs without compromising fish yield. Acknowledging the diligent efforts and ingenuity of the farmer, ICAR-CIBA provided continuous assistance throughout the cultivation phase, overseeing water quality and quantifying greenhouse gas emissions to ensure that the aquamimicry farming system is ecologically sustainable. With a high stocking density of 40 nos $m^{-2}$, 94% survivability and production of 5.53 tons were achieved. The expected production cost per kg amounted to Rs. 199, whereas the farm gate price was Rs. 330, equivalent to approximately 4.04 USD.

### Advantages of aquamimicry over biofloc technology

Both biofloc technology and aquamimicry require the addition of an external carbon source. Biofloc formation is dependent on the C:N ratio, which is close to 15:1 throughout the culture period. However, with aquamimicry, such thorough monitoring of the C:N ratio is not required. Moreover, the carbon source provided is lowered and is no longer solely dependent on nitrogen input ratios. Secondly, rather than fostering and suspending large amounts of bioflocs, sediments are removed and utilized by other species in more intensive systems. Both systems rely on external carbon sources, which serve as a foundation for the development of flocs and the production of microbial protein cells [9, 47]. Byproducts of crops and livestock are used as a source of carbon (rice, wheat, corn), glycerol, and molasses. The formation of flocs is dependent on the C:N ratio, which must be maintained at 15:1 in order to maintain the flocs with optimal expansion and growth of heterotrophic bacteria [27, 44–46, 63]. These bacteria use energy from carbon sources to absorb nutrients and thus optimize floc development [7, 8]. According to El-Sayed [26], prior to (PL) postlarvae stocking and entirely during the grow-out phase, a carbon source is supplied to keep a hC:N ratio of around 15:1. This method limits the water exchange and lessens the negative effects of harmful metabolites producing nitrogen during the growth period through the method of in situ bioremediation of water. The floccule, which is the accumulation or segregation of attached organisms such as filamentous cyanobacteria, nematodes, protozoa, phytoplankton, fungi, bacteria, etc., uneaten feed, dead and decaying matter, and excreta, can be utilized as a nutritional supplement, thus sparing the dietary protein and cutting down the feed costs for shrimp culture inputs [7, 10, 20, 33, 42]. However, in the aquamimicry system, the C:N ratio must be adjusted, and this is

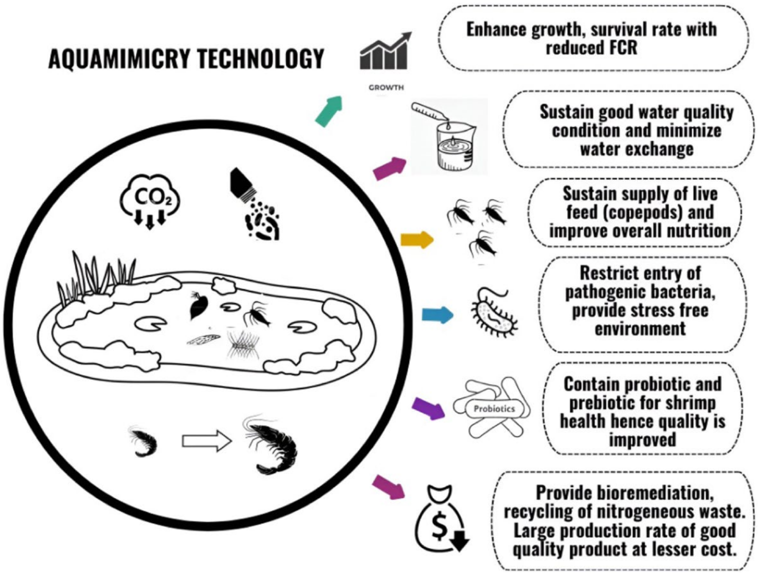

**Fig. 3** Benefits of Aquamimicry

primarily determined by the turbidity of the water. More probiotics can be inoculated during the grow-out period to boost floc production [16, 23, 64, 85]. Moreover, fluctuations in dissolved oxygen and pH were mitigated, leading to a decreased reliance on chemicals. This was achieved through the incorporation of fermented carbon sources, enhancing the stability of both zooplankton and phytoplankton populations [68]. It is important to keep in mind that for setting up the aquamimicry system, a fermented carbon source is a prerequisite, and stable plankton growth. Furthermore, the presence of a carbon source has no bearing on the amount of nitrogen, but in the context of biofloc technology to enhance the growth of heterotrophic bacteria, it is crucial to control the C:N ratio and maintain it above 10 [43, 48, 59].

In the context of shrimp farming, aquamimicry system is more sustainable than traditional systems, Fig. 3 highlites the benefits of aquamimicry technology. It slows down the formation of black soil and also reduces water quality fluctuations. Moreover, the immune competence of shrimp reared within this system was bolstered through the administration of probiotics enriched with secondary metabolites like liposaccharides and peptidoglycans. As a result, these cultured shrimp consistently exhibited superior health compared to their wild counterparts [35, 49]. The presence of different zooplankton and other livefeeds, particularly copepods, improves the feed conversion ratio. Suspended particles and waste in the system contributes to a decreased reliance on commercial feeds. Consequently, this reduction in dependency lessens the demand for biological oxygen and intensive aeration, ultimately improving the energy efficiency within the system [68]. Given the numerous advantages inherent in this system compared to BFT, the likelihood of disease outbreaks is significantly diminished. Furthermore, the nutritional value of farmed shrimp is augmented through the incorporation of live feed within the culture media. Limitations on water exchange serve to enhance biosecurity measures and mitigate stress levels. It establishes conditions that inhibit the dissemination of dangerous infections, thereby augmenting yield, mitigating costs, and bolstering profitability. Shrimp performance can be improved by simulating natural conditions in the culture system through stimulating microbial growth and flourishing phyto- and zooplankton populations, especially copepods, that can serve as a complementary foods and maintain in situ water quality [68]. Hence, the system can be deployed in both intensive and semi-intensive setups, notably aiding in the reduction of feed consumption and water exchange rates, the two key factors driving substantial input cost [16, 23]. Shrimp farming within aquamimicry systems maximizes resource utilization and minimizes waste generation. Through the integration of polyculture systems and the recycling of organic matter, such as detritus and uneaten feed, these systems optimize space and nutrient utilization while reducing reliance on external inputs. This enhances production efficiency and economic viability while minimizing the environmental impacts associated with traditional monoculture shrimp farming. Table 1 outlines the advantages and drawbacks of aquamimicry. Aquamimicry technology not only helps to achieve

**Table 1** Advantages and disadvantages of aquamimicry

| **Advantages** | |
|---|---|
| ■ Reduces water quality fluctuation | ■ Reduces black soil formation |
| ■ Good quality cultured species can be produced at lesser cost in a more sustainable manner | ■ Provides a stress-free environment |
| ■ Improves overall nutrition of the cultured species as they fed mainly on FRB and copepod | ■ Enhances the growth performance of the cultured species |
| ■ Large production rate and high market value | ■ Minimizes water exchange |
| | ■ Improves post-larvae quality |
| | ■ Decreases the feed conversion ratio |
| | ■ Decreases common disease outbreak |
| Disadvantages | |
| ■ Essential to discharge excess unwanted sediments, which cannot be recycled | ■ Use of relatively large treatment pond |
| ■ Difficult to apply in indoor culture technique | ■ High operation cost of energy input |
| | ■ Requires high level of maintenance |

sustainable aquaculture goals by limiting the use of natural resources but also promotes a viable cost–benefit ratio that is economically and socially sustainable [72]. Table 2 enlists the comparative aspects of aquamimicry over other aquaculture systems.

### Challenges and future prospects

Despite its numerous advantages, many farmers have limited reach to access such advanced technologies, infrastructure, and knowledge. Moreover, inadequate maintenance of the culture raises the risk of potential emergence of new diseases and pathogens. Also, it necessitates a large treatment pond and presents limitations in its applicability as an indoor culture method. Adequate monitoring, effective treatment of used water, responsible discharge of sewage, and meticulous handling procedures should be diligently carried out. It is recommended that soil preparation should be performed after each crop cycle, to remove sediment remains in the pond [72]. In addition to the above, when employing fermented carbon sources in aquaculture systems, it's crucial to note that these sources may contain organic acids like acetic acid and lactic acid. These acids have the potential to hinder the growth of *Bacillus* sp. or zooplankton by altering the pH and creating an environment less favorable for their development and activity. Additionally, fermented carbon sources can introduce elevated nutrient levels, potentially causing imbalances and fostering the proliferation of unwanted microorganisms or algae. When compared to biofloc-based systems, this method allegedly produced better results and performance. Nonetheless, it is essential to appropriately dispose off the excess undesired sediments that cannot be recycled. BFT and aquamimicry systems share common principles related to improving water quality, enhancing productivity, and promoting sustainability in aquaculture. While they have distinct features and approaches, there is potential for integration and synergy between the two systems.The integrated approach may enhance the resilience of aquaculture systems to environmental fluctuations, diseases and market variability by leveraging the diverse functions and interactions inherent in both the systems. However, integrating both the systems may present challenges related to system design, management, and operational complexity. Careful planning, experimentation, and adaptation may be necessary to optimize integration and achieve desired outcomes. Collaboration between practitioners, researchers, and industry stakeholders is essential to explore and refine the integration of these innovative approaches in aquaculture production systems.

## Conclusion

The aquamimicry technique epitomizes a sustainable technological paradigm integrated into both conventional and traditional farming systems, notably in shrimp aquaculture, where the synergistic application of fermented rice bran with probiotics has yielded commendable outcomes. Its sustainable, economically viable, and environmentally safe attributes are underscored by various advantages, including its minimal ecological footprint and resource efficiency, concomitant with heightened output levels. Aquamimicry represents the convergence of aquatic technologies aimed towards simulating and emulating the intricate dynamics of aquatic ecosystems to foster the production of live feed for farmed fish or shrimp. Distinguishing itself from biofloc technology, aquamimicry orchestrates meticulous carbon modulation and remains impervious to nitrogen input ratios. Employing rigorous methodologies, it efficaciously expunges and purifies sediments, subsequently repurposed by other cultivated aquatic species. These methodologies are underpinned by overarching

**Table 2** Comparative aspects of aquamimicry over other types of aquaculture system

| Aspect | Aquamimicry | Biofloc Technology | Flocponics | Traditional Aquaculture |
|---|---|---|---|---|
| Carbon sources | External sources:<br>Rice bran or wheat bran | External sources: Molasses, carbohydrates, or commercial carbon sources | External sources: Molasses, carbohydrates, or commercial carbon sources | Natural carbon inputs:Fish feed and uneaten feed<br>Supplemented by external sources:Pellets or feed additives |
| System Description | Emulates natural aquatic ecosystems under controlled conditions using heterotrophic bacteria, cultivating zooplankton blooms (especially copepods) to provide supplemental live feed for shrimp and stimulate beneficial bacteria for water quality management, nutrient cycling, and ecosystem balance | Develops dense populations of heterotrophic biofloc bacteria in culture water to assimilate organic matter and reduce ammonia, efficiently managing waste, recycling nutrients, controlling infections, and reducing the environmental impact of intensive aquaculture | Integrates biofloc technology with hydroponics, utilizing the nutrient-rich effluent from aquaculture to fertilize hydroponic crops and minimize the waste | Relies on traditional pond or tank-based systems with limited environmental manipulation or ecosystem integration |
| Disease Management | Probiotics provide synbiotic effects with fermented carbon derivatives, limit pathogenic bacteria through quorum sensing, and boost shrimp immunity | Relies on beneficial microorganisms outcompeting pathogens, improving farm biosecurity by reducing infections, animal escapes, and dependence on aqua drugs/chemicals | Maintaining balanced nutrient levels and optimizing plant health to reduce susceptibility to pathogens | Typically relies on chemical treatments or antibiotics, with limited emphasis on ecological approaches |
| Water QualityManagement | Maintains water quality through natural processes, including nutrient cycling, biological filtration, and sedimentation | Controls water quality parameters such as ammonia, nitrite, and nitrate levels through microbial activity and biofiltration | Controls water quality parameters such as ammonia, nitrite, and nitrate levels through microbial activity and biofiltration, and take up by the plants | Water quality management may involve mechanical filtration and periodic water exchanges to maintain optimal conditions |
| Economic | Initial setup costs may be high due to ecosystem modeling and habitat creation<br>Operational costs vary with system complexity and maintenance needs. Excess unwanted sediments must be discharged if not recyclable | Initial setup costs may cover equipment for biofloc production and water quality monitoring<br>Operational costs include carbon supplementation, occasional water treatment, and high electricity use | High investment in technology, equipment, and specialized labor is needed to produce fish and plants<br>Operational costs may be lower due to reduced reliance on external inputs for nutrients and water treatment, but electricity demand is high for constant aeration in biofloc fish tanks | Initial setup costs vary depending on pond or tank infrastructure<br>Operational costs may include expenses for feed (depending on intensive or semi-intensive), water treatment, and occasional disease management |
| Sustainability | Promotes environmental sustainability by reducing external inputs and minimizing impacts. Improves nutrition of cultured species fed mainly on FRB and copepods | Improves resource use efficiency and reduces environmental footprint through the recycling of organic matter and nutrients | Enhances, resource efficiency by integrating aquaculture with hydroponics, reducing water and nutrient usage while increasing overall productivity | May have higher environmental impacts due to nutrient discharge, water usage, and potential habitat degradation |

principles of holistic aquaculture management, aimed at ecosystem enhancement and biodiversity conservation for posterity. In this production paradigm, deleterious chemicals or antibiotics find no utility as inputs, ensuring the emergence of organic shrimp devoid of toxic residues or antibiotic traces or GMOs. Introducing aquamimicry technique heralds a transformative epoch in the aquaculture sphere, as species nurtured via these method evince remarkable immunological fortitude and disease resilience. This approach engenders a substantial uptick in growth efficiency. To safeguard natural biodiversity and ecosystem equilibrium, abstaining artificial or genetically engineered species remains imperative. Widespread adoption of recommended management protocols within the industry safeguards organic accreditation, species diversity, and ecosystem vitality. Future generations of aquaculturists stands poised to reap the dividends of augmented production yields of superior-quality farmed species, fostering cost-effectiveness and environmental sustainability.

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**Authors' contributions**
MD: Conceptualization, Writing-Initial draft. MM: Supervision, Writing- review and editing. NgCD: Writing- review and editing. SKS: Supervision, Writing-review and editing. WMD: Writing- review and editing. All the authors have read and approved the final version of the manuscript.

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