Microorganisms used in aquaculture

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Abstract

Microorganisms play a vital role in the health and sustainability of aquaculture systems, contributing to water quality management, disease control, and the overall productivity of aquatic farms. Beneficial microorganisms, including bacteria, fungi, algae, and probiotics, are increasingly recognized for their positive impact on aquaculture operations. These microorganisms can enhance nutrient cycling, promote the breakdown of organic waste, and reduce the need for harmful chemicals, thus improving the environmental footprint of aquaculture. Probiotics, particularly lactic acid bacteria and other beneficial strains, are used to boost the immune systems of aquatic species, reduce pathogenic outbreaks, and improve growth rates. Moreover, certain types of algae and bacteria help control harmful algae blooms and manage water parameters, contributing to healthier aquatic environments. In biofloc systems, microorganisms aid in the recycling of nutrients and conversion of organic waste into usable biomass, improving the sustainability and efficiency of aquaculture systems. The application of microorganisms also extends to disease prevention, with the use of antimicrobial peptides, competitive exclusion, and other natural mechanisms to combat bacterial, viral, and fungal infections. These biological agents offer an eco-friendly alternative to antibiotics and chemical treatments, which are increasingly subject to regulatory restrictions due to concerns over resistance and environmental contamination.

Keywords- Microorganisms, environmental contamination, aquaculture, Aquatic animals, Nitrifying Bacteria.

Introduction

Aquatic animals serve as a crucial food source for populations worldwide, with aquaculture emerging as a rapidly advancing sector that significantly contributes to national economies. As a burgeoning industry, aquaculture is poised to become a primary provider of dietary protein in the upcoming decades. Currently, it meets over half of the global fish demand, compensating for the decline in wild fish stocks caused by overfishing. Despite its growth, the industry faces significant hurdles such as disease outbreaks, environmental contamination, and sustainable production practices. Intensive aquaculture methods, characterized by high-density stocking, lead to the build-up of organic waste, uneaten feed, and excretions, which deteriorate water quality and pose risks to both animal health and the environment [1].

The accumulation of organic matter in aquaculture ponds can lead to significant variations in water quality. Excess nutrients, particularly nitrogen and phosphorus from uneaten feed and animal excretions, often promote excessive phytoplankton growth, which in turn reduces dissolved oxygen levels. This imbalance can also result in elevated concentrations of harmful compounds such as ammonia and nitrite, posing significant threats to aquatic life. Poor water quality not only stresses aquatic animals but also increases their susceptibility to infections from pathogenic bacteria and viruses. Over the past two decades, the rapid expansion and intensification of aquaculture and mariculture have exacerbated these issues. The untreated discharge of effluents from these operations, alongside industrial wastewater and sewage, has severely polluted nearby water bodies and disrupted local ecosystems. This pollution facilitates the proliferation and rapid spread of pathogenic microorganisms, leading to widespread disease outbreaks among cultured animals and substantial economic losses in the aquaculture and mariculture industries [2].

Many farmers frequently resort to antibiotics and chemicals to treat diseases in aquaculture, leading to residues in both aquatic animals and natural water sources. This practice not only impacts consumer health but also promotes antibiotic resistance among aquatic organisms. Furthermore, the discharge of wastewater laden with high levels of organic matter, antibiotics, and chemicals into public water bodies poses significant ecological risks. Such contamination can render water sources unsuitable for direct use in aquaculture, potentially leading to conflicts among different water users. The resulting environmental degradation highlights the urgent need for sustainable and responsible aquaculture practices to protect both human health and aquatic ecosystems.

The overuse of antibiotics in aquaculture and mariculture has rendered them ineffective, leading to increased bacterial resistance and disruptions in normal microbial communities, a phenomenon known as micro dysbiosis. This dual pollution results not only in ecological harm but also in antibiotic residues accumulating in aquatic products, posing risks to human health. In response, strategies such as Integrated Disease and Pest Management, which includes the use of beneficial microorganisms, have been implemented. For sustainable aquaculture and mariculture, it is essential to establish clean culture models that are free from toxins, side effects, residues, and resistance. These models should aim to enhance environmental quality, boost the immunity of cultured animals, reduce disease incidence, and maintain ecological balance [3].

Microbial Communities in Aquatic Environments

Microbes play a crucial role in the ecosystems of living organisms and their environments, significantly contributing to nutrient regeneration. In aquaculture production systems, certain microbial groups, such as bacteria and unicellular fungi, thrive and can be beneficial by converting organic matter, eliminating toxic substances, and serving as a source of microbial biomass. However, under adverse environmental conditions, these microbes can also have negative effects. The strategic application of beneficial microorganisms in aquaculture can enhance the health of aquatic animals, improve water quality, and mitigate environmental impacts, promoting a more sustainable and efficient production system.

Role of Microbes in Aquaculture

As Live Food

Live foods are crucial in aquaculture as they float in water and are readily available to fish, shellfish, and their larval stages. These live foods are often referred to as 'living nutritious capsules' because they provide all essential nutrients for healthy development, including proteins, lipids, vitamins, minerals, and carbohydrates [4].

Unlike in terrestrial animals, the use of bacteria as probiotics in fish is not limited to feeds alone. Probiotic materials, now commercially available in ready-to-use packs, are used as food supplements in fish culture, promoting growth without the need for drugs. These probiotics primarily consist of Lactobacillus and Bifidobacterium species.

Yeast, particularly *Saccharomyces cerevisiae*, can serve as a primary food source for many larvae or as feed for zooplankton cultivated for fish larvae culture. With the expansion of aquaculture, phytoplankton, zooplankton, and microalgae are increasingly important as they stimulate enzyme production and feeding in young larvae while conditioning water by extracting nitrogen compounds.

The introduction of beneficial microorganisms or non-pathogenic bacterial products, such as *Bacillus sp., Lactobacillus sp., Enterococcus sp., Streptococcus lactis, Clostridium butyricum*, and *Bifidobacterium*, into aquaculture systems enhances aquatic animal health and reduces waste. These probiotics, sourced from the digestive tracts of aquatic animals or from aquaculture pond environments, secrete enzymes like amylase, lipase, and proteinase, boosting the digestive enzyme activity and growth of aquatic animals. For instance, administering 200-300 mg of *Bacillus licheniformis* per kilogram has been shown to optimize digestive enzyme activity and growth in fry of allogenetic crucian carp.

Nitrifying Bacteria

Nitrosomonas sp. and *Nitrobacter* sp. are essential in the bioconversion of aquaculture waste, particularly ammonia, into less harmful substances such as ammonium ion (NH^{4+}), nitrite (NO^{2-}), and nitrate (NO^{3-}). Ammonium ion and nitrate serve as vital nutrients for phytoplankton and aquatic plants, supporting their growth. This metabolic process not only facilitates the reduction of toxic unionized ammonia (NH_3) in the aquatic environment but also decreases the levels of ammonium in the intestines of aquatic animals, thereby promoting a healthier and more balanced ecosystem [5].

Immune modulators

Beneficial microorganisms significantly influence the immune system of cultured aquatic animals. As non-specific immune modulators, these microorganisms enhance antibody levels and boost macrophage activity. This immunomodulatory effect helps to fortify the aquatic animals' defenses against pathogens, leading to improved overall health and resilience in aquaculture environments.

Disease Resistance

Beneficial microorganisms can significantly improve disease resistance in aquatic animals. For instance, the application of photosynthetic bacteria (PSB) has been shown to increase the survival rate of shrimp post-larvae (*Penaeus orientalis*) to an average of 58% in treated ponds, compared to only 21% in control ponds. Additionally, the types and quantities of pathogens, as well as their associated hazards, are substantially reduced in ponds treated with beneficial microorganisms compared to untreated control ponds. This demonstrates the effectiveness of beneficial microorganisms in enhancing the health and survival of aquatic species in aquaculture settings [6].

Photosynthetic Bacteria

Photosynthetic bacteria, particularly purple non-sulfur bacteria like *Rhodobacter* and *Rhodopseudomonas,* play a crucial role in the decomposition of organic matter within aquatic environments. These bacteria are versatile, thriving in both aerobic and anaerobic conditions, which enhances their utility in aquaculture systems. Beyond their role in decomposition, photosynthetic bacteria are valued for their nutritional content, which includes proteins, fats, ash, fiber, and essential amino acids. This makes them suitable as a food source for small aquatic animals, contributing to their growth and development. Furthermore, the presence of photosynthetic bacteria in aquaculture ponds helps to improve water quality by reducing organic pollutants and enhancing overall ecological balance, thus supporting sustainable aquaculture practices.

Effective Microorganisms (EM)

Effective microorganisms (EM) are identified by their characteristic brown-colored liquid with a distinct sweet and sour aroma. Comprising a blend of aerobic and anaerobic bacteria, EM includes three main groups of microorganisms: lactic acid bacteria, yeast, and photosynthetic bacteria. This synergistic combination allows EM to effectively degrade organic matter and improve water quality in aquaculture ponds. Farmers utilize EM primarily to manage and optimize the ecological balance of their ponds, contributing to healthier aquatic environments and sustainable aquaculture practices overall [7].

Microorganisms in RAS (Recirculatory aquaculture system)

Recirculatory Aquaculture Systems (RAS) rely heavily on microbial communities to maintain water quality and ensure the health of cultured species (Table – 1). In these closed-loop systems, microorganisms—especially beneficial bacteria—play a vital role in biofiltration by breaking down toxic compounds such as ammonia and nitrite, which are harmful to fish. Ammonia-oxidizing bacteria (like *Nitrosomonas* and *Nitrosospira*) and nitrite-oxidizing bacteria (such as *Nitrospira* and *Nitrobacter*) convert waste into less harmful nitrate through the process of nitrification. Additionally, denitrifying bacteria help to remove excess nitrate by converting it into nitrogen gas, which escapes harmlessly into the atmosphere. Other microbial groups, such as sulphide-oxidizing bacteria and methanogens, contribute to overall system balance by managing other by-products of organic breakdown. These microbial processes are essential for maintaining a stable, healthy aquatic environment in RAS, reducing the need for frequent water replacement and making the system more sustainable and resource-efficient.

Table -1 Microbial genera associated with major biochemical processes in recirculating aquaculture system (RAS) biofilters.

Process	**Phylum and Genus**
Nitrification	
Ammonium-oxidizing bacteria	*Nitrosomonas sp., Nitrosococcus sp., Nitrosospira*
Ammonium-oxidizing archaea	*Nitrosopumilus*
Nitrite-oxidizing bacteria	*Nitrospira sp., Nitrobacter sp.*

Denitrification	
Autotrophic	*Thiomicrospira sp., Thiothrix sp., Rhodobacter sp., Hydrogenophaga sp.*
Heterotrophic	*Pseudomonas sp., Paracoccus sp., Comamonas sp.*
Dissimilatory nitrate reduction to ammonia	*Various Proteobacteria and Firmicutes*
Anaerobic ammonium oxidation (Anammox)	*Planctomycetes sp., Brocadia sp.* *Sulphate reduction Desulfovibrio sp., Dethiosulfovibrio sp., Fusibacter sp., Bacteroides sp.*
Sulphide oxidation	*Thiomicrospira sp.*
Methanogenesis	*Methanogenic Archaea*

Microorganisms in Biofloc aquaculture system

Microorganisms (MOs) are integral components of organisms' life cycles and ecosystems, playing diverse roles within aquaculture systems. These roles can be beneficial, such as the removal of contaminants, serving as food sources for other organisms, and recycling organic matter (Table -2). However, under adverse environmental conditions, certain microbial groups can also exhibit pathogenic behaviors. Bacteria, in particular, play crucial roles in Biofloc Technology (BFT) systems by facilitating the transformation of organic materials, eliminating toxic compounds and contaminants, and serving as essential food sources for larger cultivated organisms. BFT systems foster the proliferation of both autotrophic and heterotrophic microorganisms, with beneficial heterotrophic microorganisms *like Bacillus, Acinetobacter, Sphingomonas, Pseudomonas, Rhodopseudomonas, Micrococcus, Nitrosomonas, Nitrospira, Nitrobacter, Cellulomonas,* and various yeast species being predominant. These organisms contribute significantly to bioremediation processes and enhance water quality, growth rates, performance, and overall health of the cultured organisms in aquaculture settings [8].

Table -2 Reported microbial communities associated with the cultivation of *O. niloticus*, *M. rosenbergii*, and *L. vannamei* in aquaculture systems.

Cultivated Species	**Reported microorganisms**
O. niloticus	Among protozoans, three genera, (*Paramecium, Tetrahymena* and *Petalomonas*) dominated. Four genera of rotifers were identified, (*Lecane, Trichocerca, Polyarthra* and *Asplanchna*). Only *Tubifex* was found in the group Oligochaeta.
M. rosenbergii	Periphyton communities, *Synedra, Tabellaria, Navicula, Fragilaria, Cyclotella* and *Diatoma* (Bacillariophyceae), *Chlorella, Sphaerocystes, Palmella, Pediastrum, Microspora, Oocystis, Ulothrix* and *Scenedesmus* (Chlorophyceae), *Microcystis, Anabaena, Aphanizomenon, Aphanocapsa* and *Gomphosphaeria* (Cyanophyceae), *Euglena* and *Phacus* (Euglenophyceae)
L. vannamei	*Bacteroidetes* and *Proteobacteria*, five genera of nitrifying bacteria, such as *Nitrosomonas, Nitrobacter, Nitrococcus* and *Nitrospina*, were detected. Also at genus level, *Phaeodactylibacter*, *Microbacterium* and SM1A02 were identified as biomarkers

	in indoor culture while *Marivita* was identified as biomarkers in outdoor culture

Problems related to application of beneficial microorganisms

One significant issue is the lack of differentiation among farmers between microecology and the broader ecology of microbes. It is crucial to adopt appropriate methods for applying beneficial microorganisms in agricultural practices. When implementing effective microorganisms, it becomes essential to comprehend the interactions, interdependencies, and synergies among various strains of beneficial bacteria. Furthermore, understanding synergistic elements like prebiotics—such as oligosaccharides—and additives like calcium carbonate in stable chelated states and superphosphate at specified ratios is imperative. These additions play a critical role in enhancing the efficacy and sustainability of agricultural practices, promoting healthier microbial environments and improved outcomes in agricultural production systems.

Another critical issue concerns the proper application of Effective Microorganisms (EMs). The effectiveness of EMs hinges on their timely and appropriate application in specific environments to ensure the successful establishment of beneficial microorganisms cultured in laboratories. This process requires careful consideration of factors such as environmental conditions, microbial interactions, and the overall ecosystem dynamics. By strategically timing and situating the application of EMs, agricultural practitioners can optimize their efficacy in enhancing soil fertility, promoting plant growth, and improving overall agricultural productivity while fostering sustainable agricultural practices [9].

The most significant challenge in aquaculture and mariculture is the limited understanding of microbial dynamics, necessitating expanded global research efforts. For instance, exploring the application of cyanophage—a virus that targets cyanobacteria—could effectively control harmful cyanobacterial blooms. Similarly, organisms like *Myxomycetes, Bdellovibrio, and Bacillus gemma* show promise in mitigating harmful red tides. Photosynthetic bacteria (PSB) offer potential for treating organic pollutants such as dioxins and polychlorinated biphenyls (PCBs) in water bodies crucial for sustainable aquaculture and mariculture [10].

The prospects for research on beneficial microorganisms are promising, yet the current utilization falls short of meeting the demands of cultured aquatic animals and water environment standards. Favorable conditions can lead to the dominance of harmful microorganisms, enabling rapid growth, activity, and reproduction. This scenario often results in increased populations of water-borne pathogens, which can have devastating effects on cultured species. Conversely, when conditions shift, the pathogen population can decline just as swiftly to its initial state. Addressing these dynamics requires ongoing research and application of beneficial microorganisms, alongside robust environmental management practices, to maintain a balanced microbial ecology that supports sustainable aquaculture and healthy aquatic environments.

However, current knowledge gaps indicate that existing microbial utilization methods fall short of meeting the demands for aquatic animal health and water quality standards. Unfavorable conditions can lead to the proliferation of harmful microorganisms, jeopardizing cultured species. Therefore, aligning microbial research with co-evolution, ecological principles, and microecology is essential. Developing reliable biological and ecological indicators to monitor water quality and optimizing the ecological structure of aquaculture environments can foster sustainable practices, yielding significant economic, social, and ecological benefits [11].

Conclusion

Microorganisms play an indispensable role in shaping the health, productivity, and sustainability of modern aquaculture systems. From enhancing nutrient recycling and improving water quality to strengthening the immune systems of cultured species and reducing reliance on harmful chemicals, beneficial microbes offer a natural and eco-friendly alternative to conventional aquaculture practices. Innovations such as the use of probiotics, effective microorganisms (EM), and microbial management in biofloc and recirculating systems have significantly advanced aquaculture toward a more sustainable and responsible direction. However, challenges persist—especially in terms of knowledge gaps, proper application techniques, and a deeper understanding of microbial interactions within aquatic environments. Addressing these issues through ongoing research and the integration of ecological principles will be crucial in unlocking the full potential of microbial technologies. With thoughtful implementation and continued innovation, microorganisms can serve as key allies in achieving resilient, productive, and environmentally sound aquaculture practices for the future.

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