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A REVIEW PAPER ON BIOREMEDIATION, A PANACEA TO AQUACULTURE PRODUCTIVITY

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ABSTRACT: *Aquaculture production encompasses the cultivation of aquatic organisms, including fish, shellfish, and plants, within controlled environments, playing a pivotal role in meeting the escalating global demand for fish and seafood. Various techniques are employed, ranging from fish farming in ponds, cages, or tanks to the cultivation of seaweed and other aquatic flora. The overarching objective is to achieve sustainable production while minimizing adverse environmental impacts. The utilization of bioremediation techniques in aquaculture entails harnessing microorganisms to degrade pollutants and ameliorate water quality, thereby fostering a healthier environment conducive to the thriving of aquatic organisms. Strategic interventions, such as the introduction of specific bacteria or plants capable of absorbing excess nutrients, contribute to ecosystem equilibrium, thereby promoting sustainable aquaculture practices. Leveraging living organisms to detoxify or eliminate pollutants represents a promising strategy for addressing environmental challenges associated with intensive aquaculture. The review delves into elucidating the mechanisms underlying microbial communities and selected organisms' capacity to mitigate water quality issues, notably excess nutrients and organic matter accumulation. Common bioremediation approaches encompass the utilization of beneficial bacteria, denitrifying bacteria, Nano remediation, biological filters, bioaugmentation, and oxygenation. By integrating these bioremediation techniques, aquaculture enterprises can bolster water quality, mitigate disease risks, and foster a more sustainable and productive aquatic environment conducive to the flourishing of aquatic organisms.*

KEYWORD: Bioremediation, Panacea, Aquaculture, Productivity.

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INTRODUCTION

Aquaculture is the propagation and husbandry of aquatic plants, animals, and other organisms for commercial, recreational, and scientific purposes. Aquaculture is an approximate aquatic equivalent to agriculture, that is, the rearing of certain marine and freshwater organisms to supplement the natural supply (Andres & Clyde, 2024). This includes production for supplying other aquaculture operations, for providing food and industrial products, for stocking sport fisheries, for supplying aquatic bait animals, for stocking fee-fishing operations, for providing aquatic organisms for ornamental purposes, and for supplying feedstocks to the pharmaceutical and chemical industries (Andres & Clyde, 2024). Fish farming as originally practiced involved capturing immature specimens and then raising them under optimal conditions, in which they were well fed and protected from predators and competitors for light and space. It was not until 1733, however, that a German farmer successfully raised fish from eggs that he had artificially obtained and fertilized (Andres & Clyde, 2024). Environmental and health challenges are increasing worldwide which are recognized as significant constraints on aquaculture production and trade. Indiscriminate use of chemicals in agriculture, and industrial effluents adversely affect the aquaculture and related environment. Bioremediation is one of the most rapidly growing areas of environmental biotechnology (Krishnani et al., 2019). One potential remedy for such environmental issues is the use of microbes to remove harmful pollutants from a contaminated environment. Microbial bioremediation could be advantageous with the result of formation of completely nontoxic end products, which can be beneficial for human health perspectives (Krishnani et al., 2019). Bioremediation consists of using living organisms (bacteria, fungi, actinomycetes, cyanobacteria and to a lesser extent, plants) to reduce or eliminate toxic pollutants. These organisms may be grown in a lab or they can exist naturally. Toxins including hydrogen sulfide, ammonia, and carbon dioxide cause stress and eventually sickness in shrimp due to the physical, chemical, and biological characteristics of the culture environment. The type and amount of waste generated in aquaculture farms varies based on the species raised and the techniques used in farming. The leftover food and feces, metabolic byproducts, leftover biocides and biostats, fertilizer-derived wastes, and wastes generated during molting are the several types of wastes found in aquaculture farms and collapsing algal blooms (Lakshmi, 2021).

Aquatic Toxicants and Metabolites

According to Krishnani et al. (2019), aquaculture water can come from one source or a combination of several sources such as ground water, surface water (freshwater, brackish-water and seawater) and alternative source (rain water). Based on salinity, aquaculture is classified as freshwater aquaculture, brackish-water aquaculture and mariculture. When present in higher concentrations in freshwater aquaculture systems, unionized ammonia and nitrite, two inorganic forms of nitrogen, are extremely hazardous to fish. High ammonia concentrations are typical in sewage-fed ponds, ponds with high organic matter content, and ponds with extremely high feeding rates. The proportion of ammonia increases with increase in pH and temperature of water. This adversely affects enzyme catalysis reaction and membrane stability, increases the oxygen consumption by tissues, damages gills and reduces the ability of blood to transport oxygen. Based on the length of time, the Environmental Protection Agency (EPA) has developed three categories of criteria (two chronic and one acute) for ammonia (nitrogen). The acute criterion is a pH-dependent measure of the average exposure concentration over one hour. The 30-day average concentration, which depends on temperature and pH, is one chronic criterion. A further worry regarding ammonia issues arises following a collapse in the algal community. Rapid decomposition of dead algae reduces the DO concentration and increases ammonia concentrations. Nitrogenous metabolites such as NO and N2O produced during the process of denitrification are known potent greenhouse gasses. The nitrous oxide concentration has increased in the atmosphere from 275 ppb in the 19th century to 315 ppb in the 21st century, which has mainly been attributed to anthropogenic inputs (Stress et al., 2004). Small N2O accumulation may cause destructive effects for centuries due to its long half-life of 120 years, and its 310 times more global warming potential than carbon dioxide (Trogler, 1999).

Aquaculture Components as Sources of Pollution

Aquaculture practices are often characterized by inefficiencies leading to the generation of substantial waste materials. Conventional extensive methods, while supporting limited production, necessitate expansive land utilization, which may eventually become fallow and abandoned. In contrast, modern intensive aquaculture endeavors aim for elevated production levels within compact land areas. However, this intensified approach requires significant energy inputs in the form of feed and other additives. Despite efforts to optimize efficiency, a considerable proportion of the feed, denoted as pumped-in energy, remains unutilized and accumulates as waste (Davis et al., 2021). Given the exponential growth witnessed in the aquaculture industry over recent decades, the unchecked proliferation of waste poses an imminent threat to the environment (Dauda et al., 2019). Aquaculture waste manifests in solid, liquid, and gaseous forms, broadly categorized as (i) dissolved nutrients, (ii) particulate nutrients, (iii) chemical pollutants, and (iv) pathogens. Suspended waste forms result from microbial decomposition of feed and fecal matter, settling at the bottom of aquatic systems. Principal components of sedimented solids include spilled feed, including uneaten portions, and fish feces. These sedimented waste forms constitute a substantial portion of aquaculture waste and are comparatively easier to remove from the system. Liquid waste primarily contains nutrients such as nitrates, phosphates, and excreted compounds like ammonia (Ahmad et al., 2021). Gaseous contaminants, including CO2 from respiration and methane from microbial activity, also contribute to aquaculture waste. Similar to other agricultural practices, aquaculture lacks binding policies for waste management. Nonetheless, these waste materials hold potential as feedstocks for producing value-added by-products. For instance, shrimp waste can yield chitin for chitosan production, while nutrient-rich aquaculture wastewater can support the cultivation of high-value macroalgal species.

Aquaculture Ingredients (Feed, Fertilizer and Chemicals)

In intensive aquaculture systems, fish are typically fed ad libitum, with feeding regimes ideally tailored to fish size, behavior, and water quality parameters. It is advisable to minimize feed wastage to below 5%, yet operational constraints often lead to elevated wastage rates, particularly in facilities lacking automation and monitoring capabilities. Regrettably, many farms in developing countries, which contribute substantially to global aquaculture production, face challenges in affording automation technologies (Hasan, 2001). The nitrogen-rich nature of fish feed, owing to its high protein content, results in nutrient leaching into surrounding water bodies, exacerbating environmental concerns. Common shrimp feeds, for instance, may contain approximately 40% protein content, further accentuating nutrient runoff (Rahman et al., 2017).

Bioremediation

Bioremediation, an integral facet of environmental biotechnology programs, entails the utilization of biological mechanisms to mitigate environmental contaminants, aiming to safeguard sensitive receptors. The employment of living organisms, primarily microorganisms and plants, is emerging as a promising alternative technology for removing pollutants from the environment, restoring contaminated sites, and curtailing further pollution. Natural biological processes can be harnessed to remediate nutrient-rich water by converting nutrients into forms that are more readily removable.

Bio-stimulation

Bio-stimulation involves augmenting the number or enhancing the activity of indigenous biodegradative microorganisms through the addition of electron acceptors, nutrients, or electron donors. When selecting substrates for biostimulation, a pivotal criterion is substrate cost, which, coupled with an interest in recycling byproducts, has propelled the quest for inexpensive and readily available biofilm carriers. Notably, lignocellulosic materials, such as sugarcane bagasse abound in India primarily as residues from agriculture-based industries like distilleries and sugar production. Pandey et al. (2000), and Krishnani et al. (2006a; 2006b; 2010; 2013) have successfully demonstrated the efficacy of lignocellulosic bagasse material as a biostimulant to regulate ammonia and nitrite levels in coastal shrimp aquaculture, thereby enhancing shrimp production by augmenting autotrophic nitrifying bacteria. This was further corroborated by field trials and molecular analyses conducted by Krishnani and Kathiravan (2010), which revealed increased levels of ammonia oxidizing bacteria (AOBs) in bagasse biofilm, translating into enhanced shrimp growth and production efficiency. Sugarcane bagasse holds promise as an alternative, abundant, and cost-effective bio-stimulant, facilitating Ca++ ion exchange mechanisms and supporting the biofilm growth of nitrifying consortia.

Nano remediation

Nano remediation, is an area of burgeoning exploration, exploring the operation of nanoparticles for environmental remediation. Nano-biotechnology offers innovative results to address abiotic and biotic stressors in fisheries, presenting druthers to physical, chemical, and biotechnological remediation styles. Krishnani etal. (2012) synthesized tableware-ion-changed zeolite, demonstrating its efficacy in nano bioremediation of ammonia and shrimp pathogenic bacteria. Also, conducting nano-polymers and cut- grounded amphiphilic nano-polymers have shown pledge in detoxifying Cr (VI) and flaunting bactericidal exertion (Krishnani et al., 2014; 2015). Zeolites, with their unique three-dimensional, microporous, and liquid structure, retain ion exchange parcels conducive to colorful operations in water treatment, husbandry, and monoculture. Using nano (memoir) remediation approaches holds implicit for efficiently and economically detoxifying pollutants in submarine surroundings.

Enzymatic Bioremediation (Recombinant DNA technology)

Enzymatic bioremediation, eased by recombinant DNA technology, encompasses the application of expression cloning — an abecedarian molecular biology fashion — to probe protein function. In this system, DNA garbling the protein of interest is reproduced into an expression vector, frequently containing technical protagonist rudiments to drive protein products (Alberts et al., 2002). Gene transfer among bacteria, known as gene bioaugmentation, holds pledge as a potent environmental operation tool (Pepper et al., 2002). This process entails

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the accession of enhanced exertion following gene transfer from an introduced patron organism into a member of the indigenous soil population.

Biofilters

Biofilters, also pertain to as natural pollutants, grease oxygen prolixity and give adhesion spots for the rapid-fire colonization of natural aerobic bacteria involved in nitrification and denitrification processes (Achuthan, 2000). As per Saidu (2009), biofilters are generally distributed as surfaced or submerged. Surfaced biofilters allow water to waterfall over the media, optimizing oxygen transfer and creating favorable conditions for effective nitrification. Again, submerged biofilters are entirely immersed in the bulk media, comprising quilting, liquid, and biofilm phases. These biofilters find wide operation insemi-closed recirculating systems for treating monoculture wastewater for exercise (Rijn, 2013). In similar systems, water is recirculated between a culture installation and a water treatment installation containing the biofilter. Waste accouterments are captured in concentrated backwaters, thickened to sludge, and perished by bacteria within the biofilter. The bioremediation efficacy of biofilters renders recirculating monoculture systems largely recommended for mollifying monoculture wastewater pollution in marine monoculture settings (Badiola et al., 2012), with reported waste reduction edge of over to 90. Generally employed types of biofilters include microbial mats, actuated sludge, trickling pollutants, and denitrifying pollutants.

a. Microbial mats: Microbial mats are multilayered sheets made of laminated, cohesive microbial communities that develop embedded on a polymeric gel matrix around wet submerged surfaces (Nisbet, 1999). According to D'amelio et al. (2017), the most common microbes in this environment include sulfur-reducing bacteria, purple bacteria, photoautotrophic cyanobacteria, and eukaryotic microalgae. According to D'amelio et al. (2017), the mat inoculum in waste water can be supplemented with artificial reefs, glass wool, paddy straws, or grass silage to promote the establishment of microbial mats. As a substrate for microorganisms, it is better to employ biologically degradable materials like bagasse, water hyacinth, or paddy straw (Sanin et al., 2006). According to Sanin et al. (2006), they all enhance the surface area, which promotes the quick growth of cyanobacteria bacteria that photosynthesize and naturally occur in nitrifying bacteria. Microbial mats occur in nature as stratified communities of cyanobacteria and bacteria, but they can be cultured on large-scale and manipulated for a variety of functions. They are complex systems, but require few external inputs. The functional uses of mats broadly cover the areas of aquaculture and bioremediation. Preliminary research also points to promising uses in agriculture and energy production. Regarding aquaculture, mats were shown to produce protein, via nitrogen fixation, and were capable of supplying nutrition to tilapia (*Oreochromis niloticus*). Current research is examining the role of mats in the nitrification of nutrient enriched effluents from aquaculture. Most research has addressed bioremediation, within which two majors' categories of contaminants were examined: metals and radionuclides, and organic contaminants (Judith and Peter, 2003).

b. Activated sludge: Liu et al. (2007) state that activated sludge is the most widely used biological filter for treating waste water. In order to break down organic waste, activated sludge is a type of aerated suspension that encourages microbial growth, adsorption, and agglomeration of suspended colloidal materials into microbial flocs (Haison et al., 2014). Simpler products like CO2 are produced by the bacteria' oxidation and metabolism of the nutrients present in the waste. Microbial inoculum can be created using the readily removed sludge. A longer sludge retention period guarantees increased aeration and gives the

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extracellular polymeric materials more time to settle, which increases the activated sludge's efficiency (Harrison et al., 2014).

c. **Trickling filter:** A trickling filter is a straightforward stationary bed made of gravel and stones that is designed to maximize the surface area available for microbial adhesion. The stationary bed is left open to wastewater seeping through it. According to Liu et al. (2007), the surplus nutrients and organic materials are broken down by a biologically active slime layer of bacteria formed by the flowing waste water. In terms of denitrification rate, the trickling filter has shown to be 100% effective.

d. **Denitrifying filters:** Denitrifying filters increase the conversion of nitrate to nitrogen gas by fostering the growth of anaerobic bacteria by establishing an anaerobic zone. They are made without dissolved oxygen and use cylindrical anoxic reactors fed by bacterial flocs. When garbage passes at the bottom where sludge forms, the denitrifying bacteria use the oxygen-starved environment to break down both organic and inorganic waste (Harrison et al., 2014). According to Liu et al. (2007), waste water with high nitrate contents can be treated by using denitrification filters.

Organic Detritus & Bioremediation

The dissolved and suspended organic matter, predominantly carbon chains, presents ample opportunities for microbial and algal activity (Lakshmi & Sagar, 2021). Effective bioremediation strategies necessitate the presence of microbes capable of efficiently degrading carbonaceous wastes, exhibiting rapid proliferation, and possessing robust enzymatic capabilities. Species within the genus *Bacillus,* such as *Bacillus subtilis, B. licheniformis, B. cereus*, *B. coagulans*, and *Paenibacillus polymyxa*, exemplify bacteria well-suited for organic detritus bioremediation. However, these bacteria are typically not naturally abundant in the water column, as their primary habitat resides within sediment. When introduced in adequate quantities, certain strains of Bacillus can compete with indigenous bacterial flora for available organic matter, including leached or excess feed and shrimp feces. As a form of bioaugmentation, Bacillus can be cultured, mixed with sand or clay, and dispersed to settle in the pond bottom. Additionally, Lactobacillus is utilized alongside Bacillus to facilitate the breakdown of organic detritus. These bacteria produce an array of enzymes that degrade proteins and starches into smaller molecules, subsequently utilized as energy sources by other organisms, thereby reducing water turbidity.

Phosphorous & Bioremediation

Phosphorus availability typically imposes limitations in freshwater environments. Any deviations from the normal NO3/PO4 ratio significantly influence nitrification rates or bacterial phosphorus regeneration. Phosphorus predominantly exists in organisms as phospholipids and nucleoproteins and is generated from organic compounds as PO4 by certain bacteria producing enzymes such as phosphatases and phytases. The solubility of inorganic phosphates primarily depends on pH, with bacteria capable of liberating PO4 from these compounds through the production of organic and mineral acids.

Nitrogenous Compounds & Bioremediation

Excessive nitrogen applications in aquaculture ponds can lead to water quality deterioration due to the accumulation of nitrogenous compounds, such as ammonia and nitrite, resulting in toxicity to fish and shrimp (Lakhmi & Sagar, 2021). Principal sources of ammonia include excretion and sediment flux from organic matter mineralization, as well as molecular diffusion from reduced sediment. Bacteriological nitrification, primarily achieved through sand and gravel biofilters, represents a practical method for ammonia removal from closed aquaculture systems. Ammonia oxidizers belonging to genera *Nitrosomonas, Nitrosovibrio, Nitrosococcus, Nitrosolobus,* and *Nitrospira* facilitate nitrification, producing nitrate while shifting pH towards the acidic range. Most aquaculture ponds accumulate nitrate due to the absence of denitrifying filters. These filters create anaerobic conditions where anaerobic bacteria reduce nitrate to nitrogen gas. Nitrate may undergo various biochemical pathways post-nitrification.

Biodegradation and Pollutant

Biodegradation involves the breakdown of toxic environmental pollutants into simpler molecules, often facilitated by microorganisms (Nidhi, 2023). Biodegradable matter can undergo metabolic degradation by microbes aerobically or anaerobically, with virtually any substance, living or nonliving, susceptible to biodegradation. The European Union has established a standard for biodegradability, requiring 90% degradation of the original substance to water, minerals, and carbon dioxide within six months.

Pollutants

Since the industrial revolution, the synthesis and release of highly toxic organic compounds, including fuels, polycyclic aromatic hydrocarbons (PAHs), dyes, pesticides, and synthetic chemicals like radionuclides, have posed significant challenges for natural flora in readily degrading these complex compounds (Nidhi, 2023).

Bioaugmentation

Bioaugmentation involves the application of autochthonous or allochthonous wild type or genetically modified microorganisms to polluted hazardous waste sites to expedite the removal of undesired compounds. This approach aims to enhance pollutant degradation by introducing pollutant-degrading microorganisms to contaminated sites, ultimately augmenting genetic diversity and microbial capacity. The success of bioaugmentation hinges on microbial consortia adaptation, competition with indigenous microorganisms, and various environmental factors influencing remediation efficiency. Previous studies have demonstrated the efficacy of bioaugmentation in improving soil remediation processes, particularly in environments with limited pollutant-degrading microorganisms and complex pollutants requiring multi-process remediation. Several soil parameters, including pH, temperature, moisture, organic matter content, aeration, nutrient availability, and soil type, influence the rate and success of bioaugmentation processes under natural conditions.

Significance of Bioremediation to Aquaculture Practice

Bioremediation is essential for maintaining water quality, promoting aquatic health, and supporting sustainable aquaculture production practices. Its significance extends to environmental sustainability, cost-effectiveness, and the overall well-being of aquatic ecosystems among others are:

1. **Water Quality Improvement:** Bioremediation helps remove excess nutrients, heavy metals, and organic pollutants from water, creating a healthier environment for aquatic animals.

2. **Reduced Toxicity:** Bioremediation mitigates the toxic effects of pollutants on aquatic life, reducing stress and mortality rates.

3. **Increased Biosecurity:** By removing pathogens and disease-carrying organisms, bioremediation enhances biosecurity in aquaculture systems.

4. **Improved Feed Efficiency:** Healthy water conditions resulting from bioremediation lead to better feed conversion and reduced waste generation.

5. **Enhanced Biodiversity:** Bioremediation promotes the growth of beneficial microorganisms, supporting a balanced ecosystem and increased biodiversity.

6. **Reduced Chemical Usage:** Bioremediation minimizes the need for chemical treatments, aligning with sustainable and eco-friendly aquaculture practices.

7. **Cost-Effective:** Bioremediation is often a cost-effective solution compared to traditional chemical treatments or mechanical removal methods.

8. **Environmental Sustainability:** By utilizing natural processes, bioremediation contributes to environmentally sustainable aquaculture practices, reducing the industry's ecological footprint.

CONCLUSION

Conclusively, bioremediation emerges as a promising avenue for mitigating the environmental complexities confronting aquaculture production. By leveraging microbial communities, plants, and other biological entities, bioremediation presents a sustainable and cost-efficient approach to rectifying polluted aquaculture systems. This review has elucidated diverse bioremediation methodologies, including biofiltration, phytoremediation, and microbial remediation, each offering distinct advantages in targeting specific pollutants. Furthermore, the synergistic amalgamation of various bioremediation techniques has demonstrated encouraging outcomes in augmenting remediation efficacy. Despite its potential, further investigation is warranted to fine-tune bioremediation methodologies tailored to specific aquaculture settings and pollutant profiles. Prolonged monitoring and evaluation of bioremediation effectiveness are imperative to uphold the sustainability of aquaculture production while mitigating adverse environmental repercussions. Moreover, the successful integration of bioremediation into aquaculture management necessitates collaborative efforts among scientists, policymakers, and industry stakeholders to craft bespoke solutions that account for both environmental conservation and economic viability. In essence, this review underscores the pivotal role of bioremediation as a panacea for addressing the environmental intricacies associated with aquaculture production. By harnessing the innate capabilities of biological organisms, bioremediation offers a sustainable pathway toward enhancing water quality, fortifying ecosystem integrity, and ensuring the enduring viability of aquaculture enterprises.

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