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Review Article

SUSTAINABLE AQUACULTURE; ORGANIC INNOVATIONS FOR DISEASE PREVENTION AND HEALTH MANAGEMENT IN NILE TILAPIA (OREOCHROMIS NILOTICUS)

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Abstract: *Sustainable aquaculture has become imperative in guaranteeing the enduring prosperity of aquatic farming, specifically for the Nile tilapia (Oreochromis niloticus), one of the most extensively farmed fish species. This study examines organic developments in Nile tilapia farming focused on eco-friendly practices that reduce the use of artificial chemicals and antibiotics to avoid sickness and maintain health. Integrating natural probiotics, probiotics, and immunostimulants into fish meals is one of the most critical tactics for strengthening the immune system and boosting the resistance of Nile tilapia against parasitic, bacterial, and viral infections. By maintaining the fish's natural defenses and promoting intestinal health, these natural additions lessen the need for conventional antibiotics. Moreover, the employment of beneficial microorganisms and biofiltration systems are two sustainable water management strategies that are essential for limiting the spread of illness in aquaculture settings. By emphasizing water quality through natural filtration processes, organic pond systems create a more balanced environment, lowering stress levels and disease susceptibility. By minimizing nutrient run-off, organic feed formulations using plant-based components, essential oils, and herbal extracts improve fish health and reduce the environmental effects of aquaculture techniques. This analysis also assesses these organic systems' economic viability, emphasizing how cost-effective and scalable they are compared to conventional aquaculture techniques. The aquaculture sector may minimize ecological impact while increasing fish health, producing better results, and adding to global food security through sustainable methods in Nile tilapia cultivation. To further advance sustainable aquaculture in the future, more studies are required to maximize these advances under various environmental circumstances and tilapia strains.*

Keywords: Sustainable aquaculture, Nile tilapia (Oreochromis niloticus), Organic aquaculture practices, Disease prevention, Health management, Aquaculture biosecurity

Introduction

The Nile Tilapia, or Oreochromis niloticus, is an essential component of aquaculture worldwide and is a significant driver of economic stability and food security in many developing nations (Arumugam et al., 2023). Nile tilapia, one of the most extensively cultivated freshwater fish species, is a significant participant in the world fish market due to its quick development, ability to adapt to various conditions, and reasonably cheap production costs. This species represents a vital component of the diet for millions due to its high protein content and nutritional value, especially in areas where food shortage is an issue (Wu et al., 2014). In addition to helping to end hunger, Nile Tilapia farming supports the livelihoods of major aquaculture companies and small-scale farmers by creating jobs and generating substantial economic advantages. However, the growing demand for tilapia has sparked worries about the sustainability of the environment, particularly in areas where intensive farming methods have resulted in habitat destruction, water pollution, and antibiotic abuse (Ashouri et al., 2023). This has resulted in growing interest in ecologically friendly aquaculture techniques, such as integrated multi-trophic aquaculture (IMTA), eco-friendly diets, and natural disease management strategies. Nile tilapia aquaculture is becoming more and more critical in the fight for global food security because it can reduce its ecological imprint, protect aquatic habitats, and guarantee the long-term survival of the species and the populations who depend on it by using sustainable and organic methods (Alder et al., 2012).

Because of their vulnerability to various illnesses, including bacterial infections and parasite infestations, Nile Tilapia (Oreochromis niloticus) encounters diverse problems in disease control (Li et al., 2016). Frequent bacterial illnesses that cause serious health problems, financial losses, and high death rates in aquaculture are Aeromonas hydrophila, Streptococcus iniae, and Edwardsiella tarda, which commonly afflict Nile Tilapia. The symptoms of these bacterial infections, which may spread quickly in highly crowded fish farms, frequently include bleeding, ulcerations, and systemic infections (Elbaz et al., 2024). Illness management is further complicated by parasitic infestations, such as those caused by Gyrodactylus, Ichthyophthirius multifiliis (commonly known as "Ich"), and Trichodina. Fish with significant parasite weakness are more susceptible to subsequent infections, poor feed conversion, and slower development rates (Faruk et al., 2018). Because environmental variables like poor water quality, overpopulation, and shifting temperatures may stress fish and weaken their immune systems, managing

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these illnesses is particularly difficult. Furthermore, the rise of antibiotic-resistant strains has made treatment more challenging due to the extensive and even careless use of antibiotics in managing bacterial infections (Ahmed et al., 2024). A combination of enhanced biosecurity protocols, regular surveillance, vaccination programs, and environmentally friendly farming methods that reduce stress and stop disease outbreaks are needed for effective disease control in Nile tilapia (Maulu et al., 2021).

The need for environmentally suitable substitutes for antibiotics and other chemical inputs drives agricultural and animal husbandry toward organic and sustainable methods (Golowczyc et al., 2024). The misuse of synthetic chemicals and antibiotics in farming has resulted in several serious issues, such as the emergence of germs resistant to antibiotics, damage to the environment, and worries about food safety. Probiotics, plant-based antimicrobials, and biofertilizers are examples of natural, sustainable solutions that are gaining popularity because they may improve plant and animal health without using dangerous chemicals. To preserve soil fertility and manage pests, organic farming practices, for example, strongly emphasize crop rotation, composting, and applying natural pest control techniques (Watson et al., 2002). Through preserving biodiversity, enhancing soil and water quality, and mitigating chemical discharge into natural habitats, these environmentally friendly techniques not only lessen their adverse effects on the environment but also promote the long-term health of ecosystems. Growing consumer awareness of environmental and health issues drives demand for sustainable farming practices and organic foods and spurs investment and innovation in green agriculture technology (Newman et al., 2023). The purpose of this project is to investigate sustainable aquaculture methods for Oreochromis niloticus, with an emphasis on organic improvements for disease prevention and health management. A few main goals are to evaluate natural alternatives to synthetic pesticides for disease management, determine how probiotics and organic feed affect fish health and promote environmentally friendly practices that maximize aquaculture output while causing the least environmental harm. The objective is to offer health-conscious, long-lasting solutions that may be employed in extensive Nile tilapia farming.

Organic Feed Innovations: Enhancing Immunity and Growth in Nile Tilapia

Using plant-based proteins, probiotics, prebiotics, and phytobiotics in organic feed innovations is particularly important for improving immunity and growth in Nile tilapia. The substitution of organic plant-based protein substitutes for fishmeal has been one of the most significant changes to aquaculture feed methods (Jannathulla et al., 2019). As a highly nutritious and sustainable alternative to fishmeal, soy, algae, and moringa have developed. They provide a balanced protein profile and lessen the environmental effects of fishmeal manufacturing. These plant-based proteins help tilapia develop and supply vital elements that improve fish health and promote more environmentally friendly farming methods. Simultaneously, it has been demonstrated that adding probiotics and prebiotics to organic feed greatly enhances gut health, essential for development and immunity (Adhikari et al., 2017). When combined, they improve the conditions within the fish's digestive tract and enhance their general health. Moreover, the antibacterial and antioxidant qualities of organic feed additives like phytobiotics and essential oils have drawn interest. Aquaculture routinely overuses synthetic antibiotics, and ingredients like garlic, turmeric, and other botanicals offer natural alternatives (Barad et al., 2024). These additions help tilapia fight off infections while boosting their antioxidant defenses, which lowers oxidative stress and improves growth efficiency. Several case studies have shown the benefits of organic feed formulations for fish health and farm sustainability. To illustrate, tilapia farms that have used organic feed practices report lower disease outbreaks, higher fish survival rates, and better growth efficiency, all of which add to the industry's overall sustainability. These results highlight the potential of organic feed to support more ecologically responsible and sustainable aquaculture methods while also improving the growth and immunity of Nile tilapia (Mugwanya et al., 2021).

3. Phytogenic Compounds in Disease Prevention

Plant therapies have gained much interest because of their ability to cure and prevent common ailments, including those brought on by Streptococcus infections. In particular, the use of plant extracts like neem (Azadirachta indica) and aloe vera (Aloe barbadensis) has been highlighted (Azubuike et al., 2015). These natural substitutes are increasingly being investigated for their antibacterial and health-promoting qualities in aquaculture, particularly concerning species such as Oreochromis niloticus or Nile Tilapfish. Bioactive substances include genin, Nimbin, and azadirachtin, which have antiviral, antibacterial, and antiparasitic properties and are abundant in neem extract. Aloin and emodin, two substances found in aloe vera, are recognized for their antibacterial, immunomodulatory, and anti-inflammatory properties. By acting as natural antibiotics, these extracts lower the risk of bacterial and parasite infections without having the adverse side effects of synthetic antibiotics (Hemaiswarya et al., 2008). Inhibiting enzyme systems necessary for microbial viability, rupturing bacterial cell walls, and adjusting immunological responses are just a few ways photogenic chemicals work. For example, the bioactive compounds in Neema break down microbial membranes, stop the development of biofilms, and stop bacteria from adhering to host tissues, all of which lessen the virulence of pathogens like streptococcus. By inducing the synthesis of immune cells and cytokines, aloe vera improves immune function and encourages a stronger resistance against infections (Sánchez et al., 2020). Recent studies in the aquaculture of Nile tilapia have concentrated on the effectiveness of phytogenics in lowering bacterial load, enhancing fish health, and stimulating growth. Research indicates that adding extracts from neem and aloe vera to fish feed can dramatically reduce the frequency of streptococcal infections, increase fish survival, and improve fish health.

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Studies on Nile Tilapia have shown that aloe vera promotes better gut health and nutritional absorption, whereas neem extract enhances hematological and immunological markers (Ochingo et al., 2023). More research supports these conclusions, indicating that herbal extracts may enhance fish resistance to illness by immunostimulatory effects in addition to their direct antibacterial activity. In aquaculture, phytogenics offer a viable, sustainable substitute for synthetic antibiotics, albeit more extensive research is required to standardize dosages and ensure long-term safety. This aligns with the worldwide movement to lessen antibiotic resistance and support environmentally friendly fish farming methods (Santos et al., 2018).

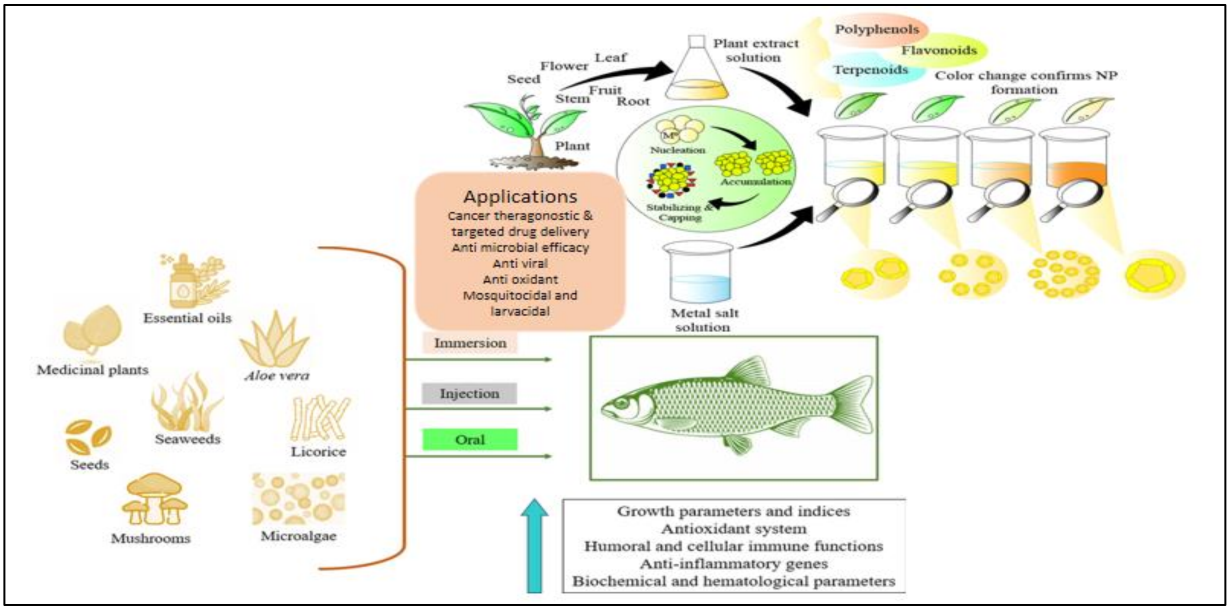

Fig 1: Phytogenic Compounds in Disease Prevention

Probiotic-Based Disease Control, a Natural Alternative to Antibiotics

In aquaculture especially, probiotics have become a viable natural substitute for antibiotics in the fight against illness. Because probiotics may support a healthy microbiome, increase immunity, and improve overall water quality, especially when cultivating species like tilapia, they are becoming increasingly important in fish farming (Tabassum et al., 2021). Probiotics have a more critical function in aquaculture than only preventing illness; they also help to preserve the natural balance of aquatic ecosystems by enhancing the quality of the water by decomposing organic waste. This is critical for tilapia health since unfavorable water quality might make fish more vulnerable to illness. Fish intestines are colonized by probiotics, which outcompete harmful bacteria and encourage the development of helpful germs that improve digestion and nutrient absorption (Li et al., 2019). Certain probiotic strains, such as Lactobacillus and Bacillus spp., have been well-researched for their beneficial effects on fish health in tilapia aquaculture. These strains increase disease resistance by boosting the fish's immune system, lowering the risk of bacterial infections, and enhancing growth performance. In particular, the Bacillus species are renowned for their capacity to generate antibiotic substances and enzymes that further impede dangerous bacteria. Probiotics are a possible replacement for conventional antibiotics in aquaculture because of these advantages (Chauhan et al., 2019).Widespread problem of antimicrobial resistance (AMR). Although antibiotics help treat bacterial illnesses, they also have the potential to cause the emergence of resistant bacterial strains, which is extremely dangerous for human and animal health (Economou et al., 2015). Multidrug-resistant bacteria have been related to the abuse of antibiotics in aquaculture. These bacteria pose a threat to fish health and can infect people through environmental or dietary routes. On the other hand, probiotics provide a more sustainable method by strengthening tilapia's natural defensive systems without causing AMR. Probiotics also assist in lowering the requirement for chemical treatments in aquaculture, supporting ecologically friendly farming methods. Probiotics are replacing antibiotics in tilapia farming, which is becoming more and more eco-friendly and organic. In this approach, illness management and growth augmentation are achieved using natural, non-synthetic means rather than artificial ones (Oladele et al., 2018). Current research trends in probiotic-based disease prevention in tilapia farming aim to determine the best strains, doses, and administration techniques to optimize probiotic effects. Several studies have shown probiotic supplements to be effective in lowering the prevalence of bacterial illnesses such as Aeromonas and Streptococcus infections, which are prevalent in tilapia farming. The synergistic benefits of mixing multiple probiotic strains to

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develop multi-strain formulations that offer more comprehensive protection against various infections are also being investigated in ongoing trials. Researchers are also looking at how probiotics could help tilapia cope with stress, as stressful environments like crowded living quarters and dirty water can impair fish immune systems and increase their susceptibility to illness. Probiotic use in organic tilapia farming is growing in popularity, emphasizing the creation of practical, affordable probiotic solutions that are simple to incorporate into current farming practices. The growing demand for fish products devoid of antibiotics is expected to take probiotics-Disease management is crucial to ethical and sustainable aquaculture methods (Chizhayeva et al., 2022).

Table 1: Probiotic-Based Disease Control, A Natural Alternative to Antibiotics

Aspect	Details	References
Key Probiotic Strains in Tilapia Farming	**Lactobacillus spp.**: Known for improving gut health, enhancing immune response, and reducing the incidence of bacterial infections. **Bacillus spp.**: Produces antimicrobial compounds and enzymes that inhibit pathogens like *Aeromonas* and *Vibrio*. Both strains are widely used to increase disease resistance and fish growth.	Kuebutornye et al., 2020
Advantages Over Antibiotics	Probiotics reduce the risk of antimicrobial resistance (AMR), which is a significant concern with the overuse of antibiotics. They naturally enhance disease resistance, reduce chemical treatment dependency, and support sustainable aquaculture practices. Probiotics do not lead to residues in fish products.	Sihag et al., 2012
Role of Probiotics in Aquaculture	Probiotics help improve water quality by breaking down organic waste and reducing harmful nitrogenous compounds. They promote a healthy microbial balance in fish intestines, which aids digestion and boosts nutrient absorption. By preventing the colonization of pathogens, probiotics enhance the immune response in fish.	Balcázar et al., 2006
Mechanism of Action	Probiotics outcompete harmful bacteria by colonizing the gut, producing antimicrobial peptides, and stimulating the fish's immune system. They improve intestinal morphology, increase mucus production, and strengthen the epithelial barrier, reducing the chances of pathogen invasion.	Ho et al., 1981
Impact on Water Quality	By breaking down organic material, probiotics help maintain better water quality, reducing ammonia, nitrites, and other toxic compounds. Improved water conditions prevent stress-related diseases and promote healthier fish populations.	Delpla et al., 2009
Reduction of Antimicrobial Resistance	Unlike antibiotics, probiotics do not contribute to developing resistant bacterial strains. This reduces the public health risk of transferring AMR pathogens to humans through the consumption of farmed fish.	Thomas et al., 2014
Applications in Organic Tilapia Farming	Organic tilapia farms increasingly rely on probiotics as a natural alternative to antibiotics. Probiotics support the organic certification process by eliminating the need for synthetic chemicals and antibiotics, aligning with eco-friendly and sustainable farming practices.	Khanjani et al., 2022
Synergistic Effects with Other Supplements	Probiotics are often combined with prebiotics (e.g., dietary fibers) to enhance their effects. This synbiotic approach maximizes gut health benefits and provides a more robust defense against pathogens.	De Souza et al., 2000

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Current Research Trends	Studies focus on optimizing probiotic strains, dosages, and delivery methods. Research is also exploring the benefits of multi-strain formulations and the potential of probiotics to enhance stress tolerance, growth performance, and disease resistance in tilapia.	Zhang et al., 2017
Challenges in Probiotic Applications	Cost of probiotic formulations, variability in effectiveness depending on environmental factors, and the need for strain-specific solutions for different pathogens. Research is ongoing to develop cost-effective and easy-to-implement probiotic strategies for widespread use in aquaculture.	Makinen et al., 2012
Future Prospects	Probiotic-based aquaculture is expected to grow as sustainability and antibiotic-free practices become more prominent. Developing genetically engineered probiotic strains tailored to specific pathogens and environmental conditions is crucial for future research.	Sahu et al., 2008

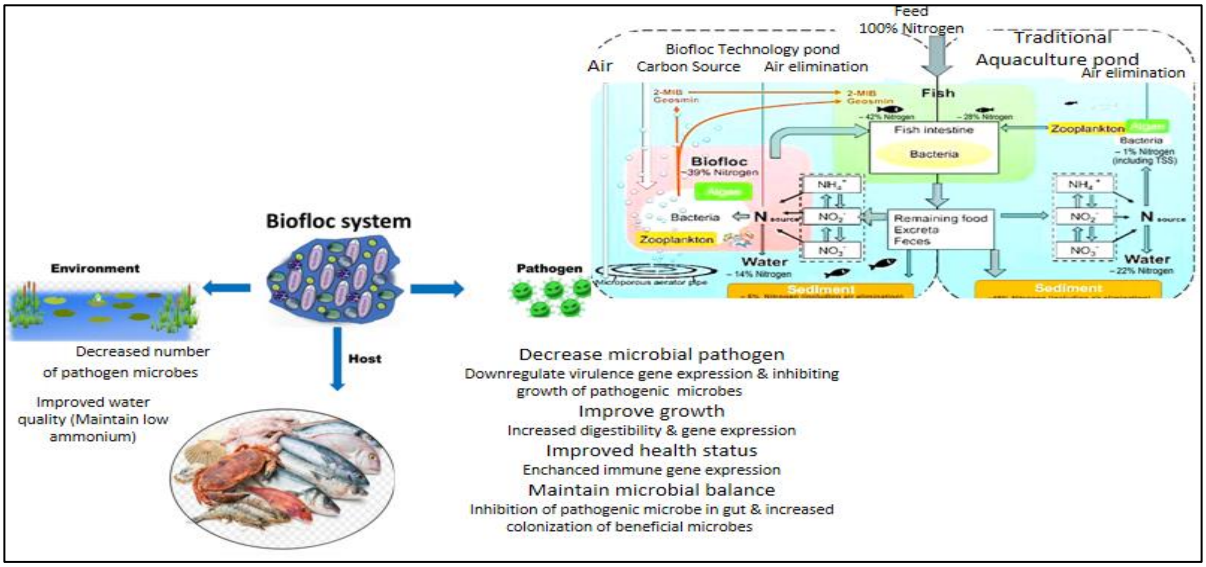

Fig 2: Biofloc Technology Sustainable Water Management and Disease Reductio

Biofloc Technology Sustainable Water Management and Disease Reduction

Aquaculture has found a sustainable answer in Biofloc Technology (BFT) since it can improve water quality, increase microbial balance, and supply natural feed, especially in water management and disease reduction. Using microbial communities, such as bacteria, protozoa, and algae, to transform surplus nutrients, such as nitrogen from fish waste, into biomass that cultured species can eat is the fundamental idea behind biofloc systems (Nisar et al., 2022). This technique acts as a rich, natural feed source that can improve growth performance in addition to preventing the dangerous buildup of nitrogenous chemicals like ammonia and nitrate. As a highly effective and sustainable aquaculture method, biofloc minimizes the need for water exchange by continually recycling nutrients. Additionally, biofloc lowers the risk of disease by fostering a balanced microbial ecology where helpful microorganisms outcompete and prevent the growth of dangerous pathogens (Lal et al., 2024). As a biological filter, the dense microbial communities in biofloc systems lower pathogen loads and improve the general health of the aquatic environment. The use of biofloc technology in the Nile

Tilapia (Oreochromis niloticus) aquaculture has produced impressive outcomes. Case studies have shown that by promoting a favorable microbial balance, bio floc systems can considerably lower the occurrence of illness, especially bacterial infections. Furthermore, bio floc has been connected to higher feed conversion ratios and growth rates, which support organic farming practices' sustainability and economic feasibility (Mugwanya et al., 2021). The adoption of more organic and ecologically friendly aquaculture methods has been bolstered by the successful integration of biofloc technology in the production of Nile tilapia, reducing the need for pesticides and antibiotics.

Additionally, because biofloc systems are closed-loop, they use less water and release less waste, which makes them a desirable solution for places with limited water supplies or strict environmental laws. Biofloc technology offers a viable, environmentally friendly alternative to disease control and water management as aquaculture expands to satisfy the increasing demand for fish worldwide. This is especially true for tilapia farming, where it increases productivity and sustainability (Boyd et al., 20

Integrated Multi-Trophic Aquaculture (IMTA): A Holistic Approach to Health Management

Integrated Multi-Trophic Aquaculture (IMTA), which emphasizes the development of many species in a synergistic and environmentally balanced system, is a transformational and sustainable approach to aquaculture (Boyd et al., 2020). IMTA creates a self-regulating ecosystem by integrating species from various trophic levels into a single aquaculture setting, boosting nutrient recycling.

Fish like shellfish, seaweed, or algae can be mixed with species like the Oreochromis niloticus) in tilapia aquaculture. The complementary responsibilities of these species are demonstrated by the waste that tilapia produce, which is used as nourishment by filter-feeding algae and shellfish, which in turn enhances water quality through natural biological filtering. By maximizing nutrient flow and establishing a balanced environment, this technique reduces the ecological footprint associated with fish farming (Henares et al., 2020). The extensive ecological services that IMTA systems offer have essential ramifications for disease prevention and general health management in aquaculture. By enhancing water quality, these systems lessen the accumulation of dangerous bacteria, parasites, and toxins, reducing the risk of sickness without the need for chemicals or medicines. For instance, algae and shellfish mitigate the effects of excess nutrients and minimize eutrophication while serving as a buffer against hazardous algal blooms. Additionally, adding a variety of species supports sustainability and overall health management in aquaculture systems by fostering a more robust ecosystem where infections are less likely to spread quickly. An interesting case study comes from Egypt's Nile tilapia farms, where the IMTA model has been effectively implemented to encourage sustainable methods. In addition to removing extra nutrients from fish waste, seaweed gives farmers another source of cash, diversifying their sources of income. Another example from Brazil shows how integrating mussel farming with tilapia farming may significantly increase fish health and water quality while lowering death rates. These illustrations highlight how IMTA has the potential to completely transform aquaculture, especially for species like tilapia that are vulnerable to disease outbreaks in conventional monoculture environments. The IMTA method promotes healthier, more productive farmed environments while lowering reliance on outside inputs, which aligns with the increasing demand for environmentally friendly and organic aquaculture (Granada et al., 2016).

Table 2: Integrated Multi-Trophic Aquaculture (IMTA) A Holistic Approach to Health Management

Table 2: Integrated Multi-Trophic Aquaculture (IMTA) A Holistic Approach to Health Management Component	Role in IMTA System	Ecosystem Service Provided	Benefits of Tilapia Farming	Case Study Example	Impact on Health Management
Tilapia (Nile tilapia)	Primary fish species produce nutrient-rich waste	Provides organic waste for lower trophic levels	High protein yield; fast-growing species	Egypt, Nile tilapia, and seaweed	Sustainable growth with reduced disease outbreaks
Shellfish (e.g., mussels)	Filter feeders consume suspended particles and phytoplankton	Biological filtration reduces excess nutrients	Improves water quality; generates additional harvest	Brazil, Nile tilapia, and mussel integration	Enhances water clarity, lowers pathogen proliferation
Seaweed/Algae	Absorbs dissolved nutrients from fish waste	Absorbs nitrogen and phosphorus, reducing eutrophication	Secondary income from seaweed harvest lowers nutrient pollution	Egypt, Nile tilapia, and seaweed integration	Prevents harmful algal blooms, enhances nutrient cycling
Biofilters	Mechanical or biological filtration systems	Removes suspended solids and pathogens	Improves overall system efficiency and reduces manual cleaning	General IMTA systems	Reduces pathogen load, promoting healthier aquatic environments
Polyculture	Inclusion of diverse species in aquaculture	Promotes balanced ecosystem with natural predator-prey dynamics	Reduces reliance on chemical treatments	China, IMTA for multi-species aquaculture	Decreases risk of disease spread due to species diversification

Probiotics	Beneficial bacteria added to aquaculture systems	Competes with harmful bacteria, improving gut health in fish	Enhances fish immunity and reduces mortality rates	India, Nile tilapia farming with probiotics	Reduces antibiotic use, supports microbial balance
Integrated water management	Reuse of water through nutrient recycling and biofiltration systems	Maintains water quality and reduces external water inputs	Reduces operational costs by recycling resources	Mexico, closed-loop IMTA systems	Promotes pathogen-free water circulation, improving overall fish health
Organic feed	Eco-friendly feed options that reduce pollution	Limits the introduction of synthetic chemicals	Ensures cleaner water and healthier fish	France, organic tilapia farming	Reduces contamination from feed, lowers stress on fish immune systems
Solar power in IMTA	Renewable energy source for powering aquaculture systems	Reduces carbon footprint, supports energy efficiency	Decreases operational costs, promotes sustainable energy usage	Spain, solar-powered tilapia farms	Lowers energy costs, ensuring more funds for health management innovations

Natural Vaccines and Immunostimulants: Emerging Organic Strategies

Promising organic solutions for disease prevention in aquaculture, especially with the Nile Tilapia, one of the most extensively farmed fish species, are provided by the creation of natural vaccines and immunostimulants. Vaccines made from plants, known as "green vaccines," are becoming a viable substitute for traditional vaccinations (Wani et al., 2022). Transgenic plants that express immunogenic proteins capable of inducing an immunological response in fish make these vaccines. These green vaccinations offer a scalable and affordable alternative to synthetic pesticides and antibiotics for disease prevention in Nile Tilapia by using the agricultural potential of plant-based systems. Fish immune responses are further enhanced by immunostimulants obtained from natural sources, such as chitosan and beta-glucans, which further complement this approach (Rodrigues et al., 2020). It has been demonstrated that beta-glucans in the cell walls of yeast, fungi, and grains stimulate the fish's innate immune system and increase its defenses against parasitic, bacterial, and viral illnesses. A substance removed from the exoskeletons of crustaceans, chitosan, has strong immunostimulatory effects by boosting phagocytic activity and cytokine synthesis. Combined, these organic immunostimulants provide a comprehensive disease prevention strategy consistent with aquaculture's sustainable methods. To establish integrated, environmentally sustainable vaccination techniques, research in this area will focus on investigating the large-scale use of these natural vaccines and immunostimulants. This includes determining the long-term impacts on fish health, maximizing the formulations for commercial tilapia farming, and researching the effectiveness of these compounds under varied environmental situations. The aquaculture business can potentially decrease its dependency on traditional medications, improve fish welfare, and advance sustainable farming methods by merging organic vaccination tactics with immunostimulants (Panigrahi et al., 2007).

Water Quality and Disease Management, Organic Approaches

Aquaculture systems depend heavily on water quality to manage illness, and organic methods are becoming more widely acknowledged for their ability to keep fish in healthy conditions. Using natural biofilters like plants, algae, and good bacteria to control and clean water is known as organic filtration (Pachaiappan et al., 2022). These biofilters function as natural cleaners by absorbing extra nutrients, decomposing organic waste, and preserving the nitrogen cycle, which stops the accumulation of dangerous compounds like ammonia and nitrite. Beneficial bacteria are essential for breaking organic matter into less dangerous molecules, keeping the water clear and healthy. Algal and aquatic plants are especially effective at absorbing nitrates and phosphates, lowering the likelihood of toxic algal blooms. In addition to enhancing the quality of the water, these organic filtration systems build a more stable and balanced environment that promotes the well-being of the fish population (Forslund et al., 2009).

Stress-induced illnesses must be reduced in addition to naturally occurring filtration by decreasing disease outbreaks through better water management. One of the leading causes of disease in aquatic species is stress, and low water quality worsens this problem by making the species more vulnerable to infections. The goal of organic methods for water management is to use natural processes rather than chemical additions to maintain ideal water parameters, such as temperature, pH, and oxygen levels (Patil et al., 2012). For instance, introducing aquatic plants to the water can naturally regulate the quantities of ammonia and nitrate while also helping to balance oxygen levels. Furthermore, controlling disease outbreaks is greatly aided by sustainable waste management and oxygenation measures. Low-energy methods that enhance oxygenation without harming the environment include solar-powered aeration devices and wind-powered water circulators. These systems raise dissolved oxygen concentrations, lessen the formation of dangerous anaerobic zones, and stop the development of waste materials that may contain diseases.

Furthermore, fish waste and uneaten feed are broken down by organic waste management techniques, including probiotics and microbial supplements, which turn them into nutrients that may be recycled within the ecosystem rather than becoming pollutants. Aquaculture systems can ultimately generate a more robust and disease-resistant environment by using organic methods for waste management, oxygenation, and water filtering (Verdegem et al., 2023). This can reduce the need for antibiotics or chemical treatments. This is advantageous for the fish's health and the long-term sustainability of aquaculture operations and sustainable farming methods that are kind to the environment. To promote healthier ecosystems and more resilient fish populations, organic methods of disease management and water quality highlight the value of interacting with natural processes instead of depending only on artificial interventions (Pelletier et al., 2020).

Ethnoveterinary Practices in Nile Tilapia Aquaculture

Using organic elements from nearby habitats, traditional knowledge passed down through generations is incorporated into Nile tilapia aquaculture's ethnoveterinary methods specifically focused on fish health management (Popoola et al., 2024). These approaches frequently require herbal and plant-based remedies to prevent and treat common fish ailments such as bacterial infections, fungal infestations, and parasite invasions. Native American fish farmers have traditionally maintained the health of their stock by using antibacterial, antifungal, and antiparasitic botanicals including neem, garlic, and turmeric. Numerous of these therapies are as effective as contemporary chemical treatments, according to research, and they also have the advantage of being less harmful to the environment and unlikely to upset aquatic ecosystems (Sharma et al., 2019). Unlike synthetic medications, which can cause resistance and the accumulation of chemical residues, ethnoveterinary treatments support a healthy, sustainable ecosystem. Including these age-old techniques with contemporary organic operations presents a workable option for disease control as the market for organic aquaculture expands. Farmers may create comprehensive health management systems that lessen reliance on chemicals and antibiotics, support organic certification procedures, and encourage long-term sustainability in Nile tilapia aquaculture by fusing ethnoveterinary expertise with modern aquaculture technology (Desbois et al., 2021).

Challenges and Future Directions in Organic Disease Prevention for Nile Tilapia

Preventing organic illness in Nile tilapia poses many intricate challenges, including balancing production and sustainability. By eschewing artificial chemicals and antibiotics, organic methods seek to improve fish health and lessen their negative effects on the environment, but there may be trade-offs (Cross et al., 1996). For example, organic therapies could need more labor-intensive procedures or be less successful in stopping disease outbreaks, which might lower overall output. Large-scale farming operations present challenges for farmers because the disease may spread quickly, challenging maintaining good yields and sustainable methods. Global aquaculture has considerable obstacles in implementing organic techniques due to regulatory and certification concerns. The certification procedures have disparities and misunderstandings since different nations and areas have different definitions of organic aquaculture (Aarset et al., 2004). Farmers of tilapia find it more difficult to reach international markets that need organic goods due to these disparities. Furthermore, being certified organic can be expensive, especially for small-scale growers. More study is necessary to ensure the success of organic disease prevention in Nile tilapia farming, especially in the areas of large-scale trials and the effectiveness of organic therapies. Scholars must investigate the enduring consequences of these techniques and devise commercially viable approaches for agriculturalists. Looking into alternative organic therapies like probiotics, herbal remedies, and better water management without sacrificing fish health or production may offer long-term fixes. Economic studies are also crucial to evaluate whether it would be financially feasible to use organic farming methods in tilapia farming widely (Cai et al., 2017).

Conclusion

A critical step toward sustainable disease management in Nile tilapia aquaculture is the development of organic solutions. Significant developments include probiotics, herbal extracts, and natural feed additives, which have shown promise in boosting fish immunity, lowering illness incidence, and limiting the need for chemical therapies. By lowering the accumulation of dangerous residues from antibiotics and other synthetic chemicals, these organic techniques encourage healthier fish and help create a more balanced aquatic ecosystem. Organic aquaculture has several long-term advantages for the environment and the industry. It provides a route towards sustainable food production by lessening the ecological imprint of fish farming, enhancing water quality, and fostering biodiversity in nearby ecosystems. Furthermore, as the demand for protein sources rises, organic techniques encourage long-term sustainability and fish population stabilization, both essential for sustaining global food security. Organic aquaculture can potentially lessen the negative consequences of traditional fish farming, such as water pollution and habitat damage, by lowering reliance on chemical inputs and promoting ecologically sensitive methods. The benefits of adopting these creative ways by the industry would help producers customers and the wider environment, ensuring the sustainability of Nile tilapia aquaculture in the future.

Conflict of interest

The authors declared the absence of a conflict of interest.

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