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Pathogenic aquatic oomycetes infecting fish: Diversity, Disease and Impact on Aquaculture

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Abstract

In aquaculture sectors across the globe, oomycetes are one of the most devastating and damaging infection caused in aquaculture sectors and led major financial loss to fish farmers. These fungus-like organisms infect a wide variety of fish including freshwater and Brackishwater exhibit significant genetic and ecological diversity. The oomycetes can infect all the life stage such as eggs, stressed juveniles and adult fish; usually causes pathological alterations such as surface mycosis, systemic granulomas, necrosis, and high mortality. Chemical treatments like formalin and malachite green are a major part of current care, although their usage is becoming more limited because of safety and environmental concerns. This has highlighted the critical need for integrated measures to control these ubiquitous diseases and sparked research into sustainable alternatives, such as enhanced husbandry, probiotics, immunostimulants, and plant-based therapies.

Introduction

Oomycetes, frequently referred to as water molds, are aquatic fungus-like organisms that may seriously infect fish. Despite having a fungus-like appearance, they are members of the Stramenopila group of organisms (Chauhan et al. 2015). These parasitic infections are prevalent in freshwater systems and become more harmful when fish are under stress due to injury, overpopulation, freezing temperatures, poor water quality, or abrupt environmental changes. The most prevalent oomycetes that infect fish are Aphanomyces and Saprolegnia species. They induce a condition known as saprolegniasis, which manifests as a white, cotton-like growth on fish skin, fins, gills, and eggs and frequently results in large losses in hatcheries and farm (Rathod et al. 2024). Cotton-like patches on the fish body have been connected to a high death rate. Farmers are affected financially by these outbreaks, especially in places where catfish and carp farming are common. All fish life stages are impacted by the illness, but eggs and larvae are particularly susceptible; losses at these stages immediately lower production yields (Kumar et al. 2022). The likelihood of disease outbreaks is increased by environmental conditions including cold temperatures, a high organic load in water, and inadequate sanitation. This is especially crucial in India, where seasonal temperature swings and monsoon-related variations in water quality are frequent. Managing oomycete infections is more difficult today because farmers lack powerful chemical tools due to the restriction on malachite green, a conventional and successful chemical management (Lindhom Letho et al. 2024). To lower losses and enhance fish health, it is essential to comprehend the variety of these oomycetes, how they infect fish, and strategies for disease prevention and management in an Indian aquaculture scenario.

Types of oomycetes infection in fish

Numerous genera of pathogenic aquatic oomycetes can infect fish at different stages of life, including eggs, larvae, juveniles, and adults. Although certain species may live in brackish water, freshwater habitats are where these organisms are mostly found. The main oomycete genera that infect fish include Saprolegnia, Achlya, Aphanomyces, Pythium, and Leptolegnia, according to taxonomy, virulence, and host choice.

Saprolegnia spp.

The most common and thoroughly researched oomycete infections of fish are *Saprolegnia* species. The two main agents that cause saprolegniasis are *Saprolegnia parasitica* and *Saprolegnia diclina*. These diseases cause distinctive mycelial growth that resembles cotton when they infect fish skin, fins, gills, and eggs (Bera et al. 2020). *Saprolegnia* infections are prevalent in ornamental fish systems, salmonid hatcheries, and carp culture. In hatcheries, where fungal hyphae spread quickly from dead eggs, egg saprolegniasis is especially damaging (Ali et al. 2019).

Aphanomyces spp.

Epizootic ulcerative syndrome (EUS), a deadly illness that affects freshwater and estuary fish throughout Asia-Pacific, is caused by highly pathogenic *Aphanomyces* species (Paria et al. 2020). Deep muscular tissues are invaded by *Aphanomyces invadans*, which results in severe ulceration and a high death rate. Treatment for *Aphanomyces* infections is quite challenging since they are invasive and systemic, in contrast to superficial infections produced by Saprolegnia.

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Achlya spp.

Fish skin and egg illnesses are frequently linked to Achlya species, which have physical similarities with *Saprolegnia*. Even though they are less aggressive, Achlya spp. can do serious harm when under stress, particularly in aquaculture systems that are not well maintained (Chauhan et al. 2015). Because these infections resemble Saprolegnia, they are frequently disregarded or misdiagnosed.

Pythium spp.

Fish eggs and larvae are sometimes infected by opportunistic infections called pythium species (Yanong, 2003). Although these oomycetes are more widely recognized as plant diseases, they can infect aquatic animals locally in the right circumstances, especially in hatchery systems with a high organic load.

Leptolegnia spp.

Leptolegnia species have been found in fish eggs and larval illnesses, despite being mostly linked to crustaceans and amphibians (Yanong, 2003). Although their exact involvement in fish sickness is still unknown, new research points to their possible significance in aquaculture settings.

Branchiomycosis spp.

In freshwater fish, particularly Indian major carps, branchiomycosis or gill rot is caused by Branchiomyces species, primarily *B. sanguinis* and *B. demigrans*. Warm temperatures, a high organic load, and poor water quality all contribute to the condition. By invading gill blood vessels, the fungus obstructs circulation and results in tissue necrosis. Fish that are infected exhibit fast breathing, discolored gills, surface gasping, and abrupt mass death. Effective pond management is the best way to prevent (Meyer and Robinson, 1973).

Fusarium spp.

Fish fusariosis is caused by opportunistic fungus called Fusarium species, such as *F. solani* and *F. oxysporum*. In stressful situations like crowded living quarters and contaminated water, infections typically enter through skin wounds. Skin sores, fin rot, cotton-like growth, and eye infections are examples of clinical symptoms. Certain species increase tissue damage by producing mycotoxins (Romadhona et al. 2025). Since there are few treatment alternatives, control depends on enhancing water quality, lowering stress, and upholding proper cleanliness.

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Control and prevention measure of aquatic oomycetes

An integrated strategy that incorporates preventative measures, environmental control, excellent management practices, and restricted treatment interventions is necessary to control pathogenic aquatic oomycetes in aquaculture. Prevention is still the best course of action since oomycete infections are frequently opportunistic and secondary. Disease control relies heavily on good aquaculture operations. Fish immunity is improved and stress is decreased by maintaining ideal water quality parameters, such as temperature, dissolved oxygen, pH, and low organic load. Skin injuries that act as entrance routes for infections can be avoided with proper stocking density, adequate feeding, and minimum handling. To stop zoospore growth, dead fish and eggs must be routinely removed.

Oomycete infections have traditionally been managed with chemical treatments, especially in hatcheries. Eggs and culture systems are frequently disinfected using substances like formalin, hydrogen peroxide, potassium permanganate, and iodophors. However, there are few possibilities for therapy because malachite green is prohibited owing to its carcinogenic properties. Concerns regarding toxicity, resistance development, and environmental pollution are also raised by excessive chemical usage. As sustainable alternatives, biological control techniques are becoming more and more popular. Through competitive exclusion and the generation of antifungal metabolites, probiotics including Bacillus, Pseudomonas, and Lactobacillus species have demonstrated inhibitory effects against Saprolegnia. Neem, garlic, and tea tree oil are among the plant-based extracts and essential oils that have shown encouraging antifungal action in lab settings. Another effective tactic is immunostimulation. Immunostimulants including vitamins, herbal additions, and β-glucans can boost innate immunity and lower vulnerability to illness. Research on the immunogenic proteins of *Saprolegnia* and *Aphanomyces* is ongoing, despite the lack of commercial oomycetes vaccines. In order to stop the introduction and spread of pathogens, biosecurity procedures such as regulated water exchange, equipment cleaning, and quarantine of new stock are essential. Infection risk is greatly decreased by hatchery-specific management, such as flow-through systems and egg disinfection.

Future perspective

Future studies on oomycete and fish fungal infections will concentrate on climate-resilient aquaculture, early identification, and environmentally friendly management. Early warning systems for farmers will be made possible by the quick, non-invasive identification of infections like Saprolegnia and Aphanomyces directly from water and fish mucus using sophisticated molecular techniques like environmental DNA (eDNA), qPCR, and

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metagenomics. It is anticipated that artificial intelligence-based disease prediction algorithms utilizing weather, agricultural management, and water quality data would assist in predicting epidemics before obvious symptoms manifest.Understanding pathogen virulence, host-pathogen interactions, and antifungal resistance will be enhanced by genomic and proteomic research, which will aid in the creation of focused therapies. Probiotics, bacteriophages, and microbiome engineering will be used more frequently in future control efforts to naturally inhibit fungus development. Promising substitutes for prohibited substances include antifungal agents derived from plants and nano-formulations. A significant area of focus for study will be the selective breeding and gene-assisted selection of fish strains resistant to fungi, particularly Indian big carps and catfish. Functional diets, immunostimulants, and possible vaccinations against important oomycetes may boost fish immunity and lessen reliance on pesticides.

Conclusion

Fish health and the viability of aquaculture are seriously threatened by pathogenic aquatic fungus and oomycetes. They are challenging to control, especially under intensive agricultural situations, because to their opportunistic character, vast spread, and high correlation with environmental stress. Future studies focusing on host resistance, early disease diagnosis, environmentally friendly treatment methods, and better farm management will be crucial. Disease outbreaks can be greatly decreased by combining probiotics, functional feeds, molecular diagnostics, and climate-resilient strategies. Reducing losses and guaranteeing sustainable aquaculture development will need using cutting-edge technology and bolstering preventative measures.

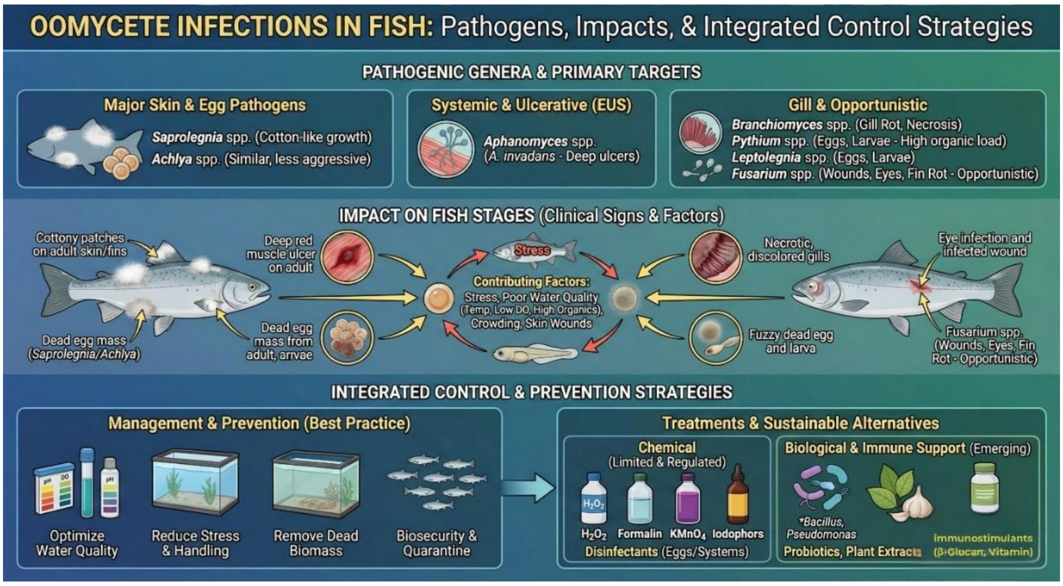

Figure 1: A systematic representation of fungal infection in aquaculture

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