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Review Article

FUNGAL DISEASES OF CULTURED SHRIMP: CURRENT STATUS AND FUTURE VIEWPOINTS

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ABSTRACT

One of the fastest-growing areas of the world's food production is shrimp aquaculture; nevertheless, fungal infections have emerged as a danger to sustainable shrimp farming, inflicting large financial losses through decreased growth, poor survival, and increased mortality. Black gill disease, larval mycosis, shell lesions, and tissue necrosis are among the diseases caused by opportunistic fungal infections such *Fusarium, Lagenidium, Haliphthoros, Sirolpidium, Aspergillus*, and *Candida* that infect shrimp at different stages of development. Fungal pathogenicity is further increased by environmental stresses as poor water quality, high organic load, excessive ammonia, salinity changes, and intense culture methods. The variety of fungal infections that afflict cultivated shrimp, their virulence mechanisms, host immune responses, diagnostic techniques, and current developments in disease management are all summarized in this review. Probiotics, which improve immunity, gastrointestinal health, and water quality while inhibiting fungal development through antimicrobial metabolites, are given special attention in biological control. Promising approaches for managing fungal diseases sustainably are also examined, including nanotechnology, phytobiotics, microbiome engineering, molecular diagnostics, and precision aquaculture. By combining these cutting-edge strategies, the reliance on chemical fungicides and antibiotics may be greatly reduced while shrimp productivity, health, and environmental sustainability are all enhanced.

Keywords: Shrimp aquaculture, Fungal diseases, Fusarium, Black gill disease, Larval mycosis.

INTRODUCTION

The sustainable development of shrimp aquaculture is significantly affected by fungal diseases, particularly under intensive farming conditions where high stocking density, environmental fluctuations, and organic matter accumulation create favorable conditions for opportunistic fungal infections. Although bacterial and viral pathogens are considered the primary causes of disease outbreaks, fungal pathogens contribute substantially to chronic mortality, reduced growth performance, poor feed utilization, and economic losses in shrimp hatcheries and grow-out farms (Ramaiah, 2006; Hatai & Lawhavinit, 2018). The fungal community associated with shrimp farming environments is highly diverse and includes several pathogenic and opportunistic genera such as *Fusarium*, *Lagenidium*, *Haliphthoros*, *Sirolpidium*, *Aphanomyces*, *Aspergillus*, *Penicillium*, *Candida*, and *Cladosporium*. These fungal organisms infect different developmental stages of shrimp, including eggs, larvae, post-larvae, juveniles, and adults, causing diseases such as black gill disease, larval mycosis, shell infections, melanization, and tissue necrosis (Lightner, 1996; Hatai & Egusa, 1978).

Virulence Mechanisms of Shrimp Pathogenic Fungi

The capacity of fungal pathogens to infiltrate host tissues, evade immunological responses, and produce extracellular enzymes that promote tissue degradation is a major factor determining their pathogenicity. Several shrimp pathogenic fungi, including *Fusarium solani*, *Lagenidium callinectes*, *Haliphthoros milfordensis*, and *Aspergillus flavus*, secrete hydrolytic enzymes such as proteases, phospholipases, lipases, chitinases, cellulases, and elastases that degrade structural proteins and lipids present in shrimp exoskeleton and epithelial tissues (Cruz da Silva *et al.,* 2011). These enzymes facilitate fungal hyphal penetration, colonization

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of host barriers, and rapid spread within internal organs. Certain fungal species such as *Fusarium solani* and *Aspergillus* spp. produce mycotoxins and secondary metabolites that interfere with cellular metabolism and suppress host immune responses. Melanin production by fungal spores provides additional protection against oxidative stress generated by shrimp immune cells, thereby increasing fungal survival within host tissues (Casadevall *et al.,* 2000). Recent genomic studies have demonstrated that fungal virulence is regulated by multiple genes involved in adhesion, extracellular enzyme secretion, biofilm formation, oxidative stress tolerance, and nutrient acquisition. These adaptive mechanisms enable pathogenic fungi such as *Fusarium*, *Lagenidium*, and *Haliphthoros* to survive and proliferate under diverse environmental conditions encountered in shrimp aquaculture systems.

Host Immune Response against Fungal Infection

Since shrimp species such as *Litopenaeus vannamei* possess only an innate immune system, they must combat fungal pathogens through non-specific defense mechanisms. The physical barriers provided by the cuticle and epithelial tissues serve as the first line of defense against microbial invasion. Following fungal penetration, cellular immune responses are rapidly activated. Hemocytes play a crucial role by recognizing fungal cell wall components such as β-glucans through pattern recognition receptors and initiating immune processes including phagocytosis, encapsulation, nodulation, and melanization (Soderhall & Cerenius, 1998).

In cultured shrimp species such as *Penaeus monodon* and *Litopenaeus vannamei*, activation of the prophenoloxidase cascade results in melanin deposition around invading fungal hyphae, thereby restricting pathogen spread and promoting wound healing. Shrimp simultaneously produce reactive oxygen species, lysozyme, antimicrobial peptides, and antioxidant enzymes such as glutathione peroxidase, catalase, and superoxide dismutase, which collectively eliminate fungal pathogens and minimize oxidative tissue damage (Amparyup *et al.,* 2013). However, prolonged environmental stress, nutritional deficiencies, poor water quality, and pollutant exposure can suppress immune responses in *L. vannamei* and *P. monodon*, increasing their susceptibility to fungal infections.

Diagnosis of Fungal Diseases in Shrimp

In shrimp aquaculture, early detection of fungal infections is crucial for reducing mortality and implementing effective disease control measures. The observation of visible symptoms such as gill discoloration, melanized lesions, cotton-like fungal growth on appendages, abnormal swimming behavior, reduced feeding activity, and soft-shell syndrome is typically the first step in the clinical diagnosis process. In commercially cultured shrimp species such as *Litopenaeus vannamei* and *Penaeus monodon*, histopathological examination remains one of the most reliable diagnostic methods because fungal hyphae can be directly visualized within infected tissues using specialized staining procedures such as Periodic Acid-Schiff (PAS) and Gomori Methenamine Silver (GMS) staining (Lightner, 1996).

Fungal colonies associated with diseases of *L. vannamei* and *P. monodon* are identified based on morphological characteristics after isolation of infected tissues on culture media such as Potato Dextrose Agar (PDA), Sabouraud Dextrose Agar (SDA), and Malt Extract Agar. Recent molecular diagnostic approaches, including polymerase chain reaction (PCR), real-time PCR, ITS sequencing, 18S rRNA gene sequencing, and next-generation sequencing, have significantly improved the speed and accuracy of fungal identification. These advanced techniques enable early detection of pathogenic fungi affecting cultured shrimp species even before the appearance of clinical symptoms (Frischer *et al.,* 2017).

Biological Control of Fungal Diseases Using Probiotics

Probiotic bacteria have gained significant attention as biological control agents against fungal infections in shrimp aquaculture due to increasing restrictions on the use of chemical fungicides. In commercially important shrimp species such as *Litopenaeus vannamei* and *Penaeus monodon*, probiotic supplementation has demonstrated potential for reducing fungal infections and improving overall health status. Beneficial bacteria including *Bacillus subtilis*, *Bacillus licheniformis*, *Lactobacillus plantarum*, *Pseudomonas fluorescens*, and *Enterococcus faecium* exhibit strong antifungal activity through the production of bioactive metabolites such as iturin, bacillomycin, fengycin, surfactin, bacteriocins, and hydrogen peroxide (Dunlap *et al.,* 2019).

These antimicrobial compounds inhibit fungal spore germination, suppress hyphal growth, and prevent biofilm formation. Probiotics enhance shrimp immunity by stimulating hemocyte proliferation, increasing antioxidant enzyme activities, improving digestive enzyme production, and maintaining intestinal microbial balance in cultured shrimp species including *L. vannamei* and *P. monodon*. Therefore, probiotic supplementation not only reduces fungal disease incidence but also improves growth performance, survival rate, feed utilization efficiency, and environmental sustainability in shrimp farming systems.

Emerging Therapeutic Strategies against Fungal Diseases

A number of novel strategies for managing fungal diseases in shrimp farming have been developed through recent advances in biotechnology. In commercially cultured shrimp species such as *Litopenaeus vannamei* and *Penaeus monodon*, nanotechnology-based antimicrobial formulations containing silver, chitosan, zinc oxide, and copper nanoparticles have demonstrated broad-spectrum antifungal activity against pathogenic fungi, including *Fusarium*, *Candida*, and *Aspergillus* species (Rai *et al.,* 2012). Similarly, phytobiotics derived from medicinal plants such as oregano (*Origanum vulgare*), turmeric (*Curcuma longa*), garlic (*Allium sativum*), and neem

(*Azadirachta indica*) possess strong antifungal, antioxidant, and immunostimulatory properties that enhance resistance against opportunistic fungal infections in cultured shrimp. Encapsulation technologies have further improved the stability, bioavailability, and targeted delivery of probiotics and antifungal compounds within the gastrointestinal tract of shrimp, thereby increasing their therapeutic efficiency (Hoseinifar *et al.,* 2018). Future developments in metagenomics, transcriptomics, artificial intelligence, and microbiome engineering are expected to facilitate precision disease management strategies and the identification of host-specific probiotic strains, contributing to environmentally sustainable shrimp aquaculture using species such as *L. vannamei* and *P. monodon*.

CONCLUSION

Fungal diseases remain an important constraint to sustainable shrimp aquaculture, causing significant reductions in growth, survival, and production efficiency, particularly under intensive farming conditions. Pathogenic fungi employ diverse virulence mechanisms that enable host invasion, tissue destruction, and evasion of the shrimp innate immune system. Early diagnosis through histopathological, cultural, and molecular techniques is essential for timely disease management and minimizing economic losses. The application of probiotics has emerged as an effective and environmentally friendly strategy for suppressing fungal pathogens while enhancing immune responses, digestive health, and overall shrimp performance. In addition, innovative approaches such as phytobiotics, nanoparticle-based antifungal agents, and advanced drug-delivery systems offer promising alternatives to conventional chemical treatments. The integration of these sustainable disease-control strategies with improved farm management practices can substantially reduce the incidence of fungal infections. Future research focusing on host-microbiome interactions, omics technologies, and precision aquaculture will further strengthen disease prevention and support the long-term sustainability of *Litopenaeus vannamei*, *Penaeus monodon*, and other commercially important shrimp species.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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