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Fungal Diseases in Fish and Treatment Methods: Trout (*Oncorhynchus mykiss*)

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Abstract **Review Article**

Trout farming plays a significant role in the global aquaculture sector and carries high economic and nutritional value. However, intensive production conditions and environmental stress factors lead to the emergence of various diseases in fish. Among these diseases, fungal infections, particularly saprolegniosis caused by Saprolegnia species, cause significant losses in trout farming. Fungal pathogens cause lesions on the skin, fins, and gills of fish, paving the way for both direct and secondary infections. Water quality, stocking density, and environmental factors play a critical role in the spread of diseases. While existing chemical antifungal treatments are effective, challenges such as environmental effects and drug resistance necessitate the development of natural and sustainable alternative treatment methods. In this context, biosecurity measures, natural antifungal agents, and immune-supporting approaches are becoming increasingly important in protecting fish health. This article comprehensively reviews the etiology, diagnosis, epidemiology, and current treatment strategies of fungal diseases in trout, and offers recommendations for sustainable fish farming.
Keywords: Trout, fungal infections, pathogen, treatment.

1. INTRODUCTİON

The aquaculture sector has become a rapidly growing and developing food production sector worldwide in recent years (Action, 2020). Rainbow trout (*Oncorhynchus mykiss*), one of the most important species raised in freshwater aquaculture, is preferred by producers due to its rapid growth rate, high market value, environmental tolerance, and the nutritional value its meat provides (Buchmann, 2022; Qadir *et al.,* 2024). However, infectious diseases encountered in the production of this species, especially fungal infections, lead to serious economic and biological losses (González-Palacios *et al.,* 2020). Fungal diseases emerge and spread rapidly, particularly in conjunction with factors such as overstocking, poor water quality, environmental stressors, trauma, and immunosuppression (Van West, 2006; Liu *et al.,* 2016). These infections develop when pathogen spores, free in the aquatic environment, adhere to and multiply on the mucosal tissues of fish (Greco *et al.,* 2015). Clinical signs such as lesions covered with cotton-like structures, fin erosion, gill damage, and general behavioral disturbances are typically observed in infected individuals (Jones *et al.,* 2014). Saprolegnia parasitica is among the most common fungal pathogens in aquaculture (Najafipoor, 2011). This oomycete species can rapidly infect fish eggs and individuals with damaged skin, causing significant egg losses, particularly in hatcheries (Özcan & Arserim, 2022). Other pathogens, such as Ichthyophonus hoferi, form nodules in muscle tissue and cause systemic infections, particularly in adult fish, leading to death (Sarkar *et al.,* 2022).

Chemical agents commonly used in the past to treat such infections, particularly substances such as malachite green, formalin, and potassium permanganate, have been banned or restricted over time due to their toxic effects and environmental damage (Qadir *et al.,* 2024). The DNA damage caused by substances such as malachite green and their teratogenic and carcinogenic effects in fish have influenced these decisions (Özdemir, *et al.,* 2022; Sarkar *et al.,* 2022). As a result, research on alternative methods such as natural products, plant extracts, probiotics, and immunostimulants has increased in recent years (Kumar *et al.,* 2020; Rocchi *et al.,* 2017).

Even simple chemical compounds such as boric acid have been shown to inhibit the germination of S. parasitica spores in vitro and in vivo, demonstrating the possibility of less environmentally damaging chemical approaches (Ali *et al.,* 2019). Furthermore, extracts of plants such as garlic and onion have been reported to significantly reduce the rate of fungal infection in eggs (Özdemir, *et al.,* 2022). As natural biological agents, probiotic bacteria such as Pseudomonas fluorescens can be effective in combating pathogens by supporting fish immunity (Rocchi *et al.,* 2017).

With the development of molecular diagnostic methods, the diagnosis of fungal infections has also significantly accelerated. In particular, qPCR (quantitative polymerase chain reaction) and environmental DNA (eDNA)-based screening systems can detect the presence of pathogens in the aquatic environment at an early stage, thus preventing the spread of the disease (Rocchi *et al.,* 2017). This provides a significant advantage, especially for hatcheries and businesses with high stocking densities (Kumar *et al.,* 2020; Lieke *et al.,* 2020).

Fungal disease control in trout production should be considered not only as a treatment-oriented process but also as an integrated health management plan based on preventing disease occurrence (Buchmann, 2022). In this regard, factors such as biosecurity practices, water quality management, quarantine protocols, and the hygiene of feed sources should be considered (Qadir *et al.,* 2024). This review aims to comprehensively address fungal pathogens encountered in trout farming, their transmission routes, clinical effects, and treatment approaches developed against these infections, particularly in light of recent studies conducted after 2015 (Buchmann, 2022). Furthermore, by proposing alternative and sustainable solutions, it aims to promote methods that are both environmentally sound and economically viable for producers (Rocchi *et al.,* 2017; Lieke *et al.,* 2020).

2. Definition and Epidemiology of Fungal Agents

Aquatic environments are ecosystems rich in microorganisms, and fish living in these environments are exposed to many pathogenic microorganisms (Qadir *et al.,* 2024). Fungal pathogens, in particular, cause opportunistic infections, leading to significant mortality in high-economic species such as trout (Buchmann, 2022). Fungal infections are generally more common in individuals with weakened immune systems, those under stress, or those with damaged outer skin (González-Palacios *et al.,* 2020). A thorough understanding of the definition and epidemiology of such infections is crucial for developing effective control and treatment strategies (Refai *et al.,* 2016). The genus Saprolegnia stands out among the most common causes of fungal infections in freshwater fish (Ali *et al.,* 2014). Saprolegnia parasitica is classified as a highly pathogenic oomycete and, unlike true fungi, contains cellulose instead of chitin in its cell walls (Lieke *et al.,* 2020; Van West, 2006). Oomycetes more easily infect in environments where water quality deteriorates, temperature drops, and physical damage occurs (González-Palacios *et al.,* 2020). Damage to the mucus layer on the outer surface of fish, in particular, facilitates the attachment of fungal spores to the tissue and the initiation of infection (Kumar *et al.,* 2020; Buchmann, 2022). Saprolegnia parasitica spores can be found in the environment as both zoospores (swimming spores) and aplanospores (non-motile spores). When suitable environmental conditions occur, they rapidly attach to host tissues and initiate mycelial development (Qadir *et al.,* 2024). Fish eggs, in particular, are highly susceptible to this pathogen, and if infection is not diagnosed early, it can quickly spread throughout the entire egg mass (Özdemir *et al.,* 2022). This leads to significant reductions in hatchery productivity and causes significant economic losses to producers (Kumar *et al.,* 2020).

Another important fungal-like agent is Ichthyophonus hoferi. This pathogen is actually a protist and is classified in this group because it exhibits fungal-like pathogenesis (Jones *et al.,* 2014). Ichthyophonus infections are generally systemic, forming nodular structures in internal organs, particularly the liver and kidneys, leading to chronic infection (González-Palacios *et al.,* 2020). Infected fish appear weak, lose weight, and often move slowly, making the infection easily recognizable within the fish stock (Qadir *et al.,* 2024). From an epidemiological perspective, fungal pathogens are primarily transmitted environmentally, spreading through water and contact (Lieke *et al.,* 2020; Rocchi *et al.,* 2017). Biofilm formation, particularly in production tanks, allows spores to survive for extended periods and can prevent complete spore elimination even during cleaning operations (Buchmann, 2022). In addition, decreasing water temperature (usually 10–15°C) is an important factor in the increase of fungal infections, because low temperature both suppresses fish immunity and facilitates the development of the pathogen (Ali *et al.,* 2019; Kumar *et al.,* 2020).

The high environmental resistance and rapid germination of Saprolegnia spores make infection prevention difficult (Van West, 2006). The mobility of zoospores, in particular, allows spores to be carried long distances by water currents, facilitating spread (Lieke *et al.,* 2020). Furthermore, spores released from infected individuals come into direct contact with healthy fish, completing the transmission chain (Rocchi *et al.,* 2017; Buchmann, 2022).

One of the epidemiological characteristics of fungal agents is that they often cause secondary infections in fish (González-Palacios *et al.,* 2020). This means that the fish often first must be exposed to trauma, a parasite, or a bacterial infection, facilitating the pathogen's entry point (Qadir *et al.,* 2024). However, recent studies have shown that some Saprolegnia species may be primary pathogens, necessitating more careful monitoring of these species (Van West, 2006; Kumar *et al.,* 2020).

In addition, in addition to environmental stress factors, management problems such as overstocking, sudden water changes, oxygen deficiency, poor feed quality, and poor hygiene conditions also directly impact the emergence of fungal infections (Kiryu *et al.,* 2017; Rocchi *et al.,* 2017; Buchmann, 2022). Therefore, control of fungal diseases should include strategies not only targeting the pathogen but also addressing environmental and management factors (Özdemir *et al.,* 2022; Qadir *et al.,* 2024).

In light of all this information, the identification of fungal agents and a detailed understanding of their transmission routes are essential for both preventive medicine and sustainable aquaculture (Lieke *et al.,* 2020). Optimizing environmental conditions, along with early diagnosis and appropriate hygiene practices, plays a key role in preventing the spread of these diseases (Rocchi *et al.,* 2017).

3. Clinical Signs and Diagnostic Methods

Fungal diseases are one of the most common infectious problems in trout farming, and their clinical symptoms are generally identified by visible lesions and behavioral changes (Khan *et al.,* 2025). The most prominent clinical finding, particularly in Saprolegnia parasitica infections, is the formation of whitish, cotton-like mycelia in the infected area (Sharma *et al.,* 2023). These mycelia are often visible on the fish's fins, skin surface, around the eyes, and gills, and over time, they spread and cause tissue loss (González-Palacios *et al.,* 2020).

In the initial stages of fungal infections, fish exhibit general stress symptoms such as loss of appetite, impaired swimming behavior, staying near the water surface, and excessive gill movement (Iqbal & Khatoon, 2019; Qadir *et al.,* 2024). Although these behaviors are nonspecific, they can be confused with other diseases, so detailed analysis of clinical findings is important in the diagnostic process (Jones *et al.,* 2014). Necrosis, ulcerative skin lesions, and increased mucus are observed, especially in later stages, on the tail and fin edges of fish (Yanong, 2003; Nissa *et al.,* 2024). Because lesions usually occur after mechanical trauma, these areas are the first areas where infection is observed (Arslan *et al.,* 2025).

Fungal infections in fish eggs pose a significant risk, especially during the hatchery period. Saprolegnia species develop by adhering to the eggshell, leading to embryonic death (Tomczyk *et al.,* 2018). Discoloration, opacification, and a collapsed appearance are common in affected eggs. Furthermore, because infected individuals in eggs become a spore source, the infection quickly spreads to other eggs, causing significant losses at the flock level (Oono *et al.,* 2007). In agents that cause systemic infections, such as Ichthyophonus hoferi, symptoms are more commonly observed in the internal organs. Systemic symptoms such as swelling in the fish's body cavities, nodule formation in muscle tissue, and enlargement of the liver and spleen are common (Jones *et al.,* 2014). These infections are generally chronic, slowing the fish's growth rate, impairing body condition, and can result in sudden death (Anokhina *et al.,* 2023; Qadir *et al.,* 2024).

The diagnostic process begins with clinical observations. During histopathological examinations, fungal elements in the tissues can be demonstrated with special stains. Fungal hyphae can be clearly observed within the tissues, particularly with Periodic Acid-Schiff (PAS) and Grocott-Gomori methanamine silver (GMS) stains (Rahman *et al.,* 2017). These methods are highly reliable in detecting fungal pathogens and allow assessment of the depth of invasion in infected tissues (Russell Danner & Merrill, 2005).

Digital imaging techniques have also begun to be used as an auxiliary diagnostic tool in recent years. Artificial intelligence-supported image analysis systems, in particular, have made it possible to automatically identify and classify skin surface lesions (Qadir *et al.,* 2024). These systems contribute to controlling the spread by enabling the rapid identification of infected individuals, especially in businesses with intensive production (Liu, *et al.,* 2020). Among the practical methods used for field diagnosis, rapid test kits, particularly lateral flow immunoassay (LFIA) kits based on antigen recognition, stand out (Buchmann, 2022). These tests are generally developed for common fungal pathogens such as Saprolegnia and offer the advantage of providing results within a few minutes. However, it should be noted that these rapid tests applied in the field are not as sensitive as laboratory techniques (Lindholm-Lehto, & Pylkkö, 2024).

In some cases, fungal infections can coexist with secondary infections. For example, fungal infections developing alongside bacterial pathogens such as Aeromonas hydrophila can lead to confusion in diagnosis (Ali *et al.,* 2019). Therefore, a multifactorial assessment should be performed during the diagnostic process and, if necessary, combined with bacteriological tests (Kumar *et al.,* 2020).

Evaluation of environmental parameters is also very important in the diagnostic process. Factors such as water temperature, pH, dissolved oxygen level, and ammonia and nitrite concentrations are important factors in the detection of fungal infection. It plays a decisive role in the emergence of fungal spores (Yeasmin *et al.,* 2015). Decreasing water temperature, in particular, both weakens the fish's immunity and encourages the development of fungal spores. Therefore, when making a diagnosis, it is necessary to consider not only the pathogen but also environmental stress factors (Newman, 2021).

An effective diagnostic strategy requires a combined evaluation of clinical observation, microscopic examination, culture methods, molecular diagnosis, and environmental analyses (Lindholm-Lehto & Pylkkö, 2024). Early detection of infections and protection of herd health are possible, especially in production facilities, through routine checks (Qadir *et al.,* 2024). Developing diagnostic technologies offer the opportunity to detect infections before symptoms begin, contributing to more effective preventive practices in the future (Newman, 2021).

In conclusion, while the clinical symptoms of fungal infections in trout are quite characteristic, they can also include symptoms that can be confused with other diseases. Therefore, an effective diagnostic approach requires a multidisciplinary approach, considering the type of pathogen, its rate of spread, and the impact of environmental factors. Today, thanks to developing diagnostic technologies, it has become possible to detect infection at an early stage and direct treatment (Liu *et al.,* 2016; Qadir *et al.,* 2024).

4. Treatment Methods and Applications

Treatment of fungal diseases in trout farming varies depending on the pathogen type, the prevalence of infection, and environmental conditions (Srivastava *et al.,* 2023). Environmental management strategies, particularly for controlling water quality-sensitive pathogens such as Saprolegnia, are combined with chemical and biological treatments (Ali *et al.,* 2019; Rocchi *et al.,* 2017). Currently, intensive research is being conducted on both traditional treatment methods and environmentally friendly alternatives (González-Palacios *et al.,* 2020).

The most widely used traditional treatment method is formalin baths. Formalin (an aqueous solution of formaldehyde) has been the antifungal agent of choice for the treatment of fish diseases for many years (Van West, 2006). It is generally applied as short-term baths at a concentration of 0.1–0.2% and is effective in removing fungal spores from surfaces (Ali *et al.,* 2019; Kumar *et al.,* 2020). However, formalin's use has been restricted in many countries due to its toxic effects, environmental persistence, and potential harm to human health (Jones *et al.,* 2014; Srivastava *et al.,* 2023).

In addition to formalin, oxidizing and antiseptic agents such as hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), and sodium chloride (NaCl) are also widely used. Hydrogen peroxide is effective against both fungal spores and bacteria and can be used safely in short-term baths (Liu *et al.,* 2016). Success has been reported, particularly against Saprolegnia infections, when applied at doses of 100–500 mg/L (González-Palacios *et al.,* 2020). Potassium permanganate, thanks to its strong oxidant structure, oxidizes organic matter on the surface of the fish, making it difficult for fungal mycelia to adhere to the surface (Ali *et al.,* 2019; Rocchi *et al.,* 2017).

The key point to consider when using antifungal chemicals is their ability to suppress the pathogen without harming the target organism. High concentrations can cause gill damage, increased mucus production, and behavioral disorders in fish (Ali *et al.,* 2019; Srivastava *et al.,* 2023). Therefore, treatment protocols are generally adjusted according to water temperature, pH, and fish size (Van West, 2006; Liu *et al.,* 2016).

In recent years, natural products and herbal extracts have been considered important alternatives in antifungal treatment. In particular, the antifungal effects of extracts of plants such as garlic (*Allium sativum*), ginger (*Zingiber officinale*), and thyme (*Thymus vulgaris*) have been demonstrated under laboratory conditions (Kumar *et al.,* 2020; Rocchi *et al.,* 2017). These products are also prominent for their immune-supporting properties in fish. For example, garlic extract has been reported to both inhibit the growth of Saprolegnia mycelia and support the immune system by increasing leukocyte and lysozyme levels in fish (Ali *et al.,* 2019).

Propolis, a natural substance among bee products, has been used in fish health in recent years, particularly for its antifungal and antimicrobial properties. The flavonoids and phenolic compounds contained in propolis damage the fungal cell wall, preventing mycelial growth (González-Palacios *et al.,* 2020; Srivastava *et al.,* 2023). Furthermore, the immune modulation effect of propolis on the fish's stress response is considered supportive of treatment (Jones *et al.,* 2014).

In addition to herbal products, probiotics are also considered supportive in antifungal control. Lactobacillus and Bacillus species both improve the overall health of fish by regulating the intestinal flora and exert a direct antifungal effect by preventing pathogen attachment (Rocchi *et al.,* 2017; Ali *et al.,* 2019). In vitro studies have shown that Bacillus subtilis strains, in particular, inhibit the growth of Saprolegnia mycelia (Liu *et al.,* 2016; Kumar *et al.,* 2020).

In addition to pharmaceutical treatments, improving environmental conditions and improving water quality play an important role in combating infection. Reducing ammonia and nitrite levels, optimizing oxygen levels, and reducing organic load suppress the development of fungal spores (González-Palacios *et al.,* 2020; Srivastava *et al.,* 2023). Additionally, maintaining a constant water temperature and avoiding sudden temperature changes prevents the fish's immune system from being suppressed (Ali *et al.,* 2019).

Another treatment strategy is the use of immunostimulants. Beta-glucans, mannan-oligosaccharides, and vitamin supplements, in particular, reduce the effects of fungal infections by increasing phagocytic activity and innate immune responses in fish (Ali *et al.,* 2019; Kumar *et al.,* 2020). Increases in leukocyte count, serum lysozyme, and complement activities have been observed in fish supplemented with beta-glucan (Liu *et al.,* 2016). While such practices do not have a direct antifungal effect, they are crucial in controlling the spread and severity of the disease (Srivastava *et al.,* 2023). Nanotechnology applications are also beginning to be integrated into modern aquaculture treatment. Silver nanoparticles (AgNPs) are used in fish health research due to their antifungal properties and are considered a potential solution against aquatic fungi such as Saprolegnia (Rocchi *et al.,* 2017; González-Palacios *et al.,* 2020). Silver nanoparticles disrupt the fungal cell wall, disrupting cell integrity and inhibiting metabolic processes (Ali *et al.,* 2019). However, the long-term effects of such technologies on the environment and human health have not yet been clearly established, and therefore, controlled use is crucial (Van West, 2006; Liu *et al.,* 2016).

Meanwhile, vaccines have also been evaluated in recent years as preventive treatments against fungal infections. However, while highly effective against bacterial and viral diseases, vaccines have not yet achieved widespread clinical success against fungi. This is primarily due to the difficulty of targeting fungal pathogens due to their multicellular structure and antigenic diversity (Rocchi *et al.,* 2017; Kumar *et al.,* 2020). Recombinant proteins, mycelial wall-derived glucans, and subunit vaccines developed against cell surface proteins used in experimental vaccinations have shown promising results; however, further studies are needed to confirm the efficacy of these vaccines under field conditions (Ali *et al.,* 2019; Srivastava *et al.,* 2023).

Another factor to consider when planning treatment strategies is the pathogen's potential for developing resistance. In particular, it has been observed that some Saprolegnia species develop antifungal resistance following repeated applications of formalin or potassium permanganate (González-Palacios *et al.,* 2020). Therefore, cyclical treatment protocols or combined treatment approaches are recommended instead of prolonged and frequent use of the same chemical (Van West, 2006; Jones et al, 2014).

Biofilms also play a significant role in the chronicity of fungal infections. Fungal pathogens can adhere to surfaces, become protected within the biofilm structure, and become resistant to treatment (Ali *et al.,* 2019). Therefore, regular hygiene practices such as surface cleaning, filter changes, and water disinfection are essential in treatment plans to break down biofilms (Liu *et al.,* 2016; Srivastava *et al.,* 2023). Some studies have reported that ultraviolet (UV) light and ozonization systems also prevent fungal spores from becoming active in water and reduce systemic spread (Kumar *et al.,* 2020; Rocchi *et al.,* 2017. UV light systems, especially when used in the influent water of production systems, are effective in preventing infection transmission into the system. Ozonation both disinfects water and oxidizes dissolved organic matter, making it difficult for pathogens to feed (González-Palacios *et al.,* 2020).

Finally, biological control methods are among the promising alternatives for treating fungal diseases. In particular, mycoparasitic fungi and some naturally occurring antagonistic microorganisms suppress the growth of fungal pathogens and prevent infection through competition (Srivastava *et al.,* 2023). For example, mycoparasitic species such as Trichoderma harzianum have been shown to attack Saprolegnia hyphae and disrupt their structural integrity (Ali *et al.,* 2019; Kumar *et al.,* 2020). Such applications offer environmentally friendly solutions, especially in systems aiming for sustainable aquaculture.

When all these treatment methods are evaluated, it becomes clear that no single method is sufficient in all circumstances. The most successful results are achieved with holistic approaches that integrate environmental management, hygiene, chemical, and natural treatments (González-Palacios *et al.,* 2020; Liu *et al.,* 2016). In this context, producers should select appropriate strategies based on current disease risk, base treatment protocols on scientific principles, and prioritize preventive practices (Ali *et al.,* 2019; Rocchi *et al.,* 2017).

5. Preventive Measures and Sustainable Approaches

Another element in combating fungal infections in aquaculture systems is protective strategies aimed at preventing disease outbreaks, as important as treatment. Water quality control, hygiene practices, and immune-supportive practices, particularly in trout production systems, play a critical role in preventing the spread of fungal pathogens (Mostafa*et al.,* 2020; Srivastava *et al.,* 2023). Given that fungal infections are triggered by environmental stress factors, preventive approaches directly impact production efficiency and sustainability (Xu *et al.,* 2020).

The most fundamental preventive measure is the sustainable management of water quality. High organic load, low dissolved oxygen levels, sudden temperature changes, and insufficient water flow, in particular, facilitate the proliferation of opportunistic pathogens such as Saprolegnia (Rocchi *et al.,* 2017). Practices such as maintaining a constant water temperature between 10–15°C in the production system, regularly monitoring nitrite and ammonia levels, and filtering total suspended solids can prevent fungal spores from becoming active (González-Palacios *et al.,* 2020; Noga, 2010).

Mechanical cleaning and system disinfection are also effective preventative methods for preventing the spread of fungal infections. Regular disinfection of tank walls, equipment, hatchery baskets, and hand tools prevents biofilm formation and pathogen proliferation (Ali *et al.,* 2019; Van West, 2006). Methods such as hypochlorite compounds, iodine-based disinfectants, and ozonization can be used to inactivate spores found on surfaces. However, the frequency of disinfection and the concentration of the agent used should be implemented without disrupting the biological balance of the system (Liu *et al.,* 2016; Srivastava *et al.,* 2023).

Biosecurity measures in production facilities are also critical in preventing the spread. Practices such as restricting visitors, using protective equipment by workers, controlling fish entrances and exits, and filtering water intakes to prevent pathogen entry are considered within the scope of biosecurity (Rocchi *et al.,* 2017; Kumar *et al.,* 2020). Furthermore, the rapid removal of dead fish from the system, isolation of infected individuals, and proper disposal of waste reduce the spread of infection among fish (Ali *et al.,* 2019).

Stress management is also an important part of preventive approaches. In cold-blooded creatures like trout, environmental stress causes immune suppression and the establishment of infection by opportunistic pathogens (González-Palacios *et al.,* 2020). Reducing stress factors such as dense stocking, sudden water temperature changes, inadequate feeding, and transportation helps fish maintain resilience (Heikkinen *et al.,* 2013). Providing immunostimulant supplements, especially after transportation, can be effective in preventing infection (Liu *et al.,* 2016; Kumar *et al.,* 2020).

Nutritional management also plays an indirect but effective role in preventing fungal diseases. A balanced diet supports the fish's overall health and contributes to the optimal functioning of their immune systems (Srivastava *et al.,* 2023). Antioxidant vitamins, particularly vitamins C, E, A, and D, strengthen the immune system and provide resistance to fungal infections (Ali *et al.,* 2019). It is also important that feeds are mycotoxin-free and stored under appropriate conditions, as contaminated feeds can suppress immunity and predispose to infections (Van West, 2006).

Regular use of probiotics and prebiotics, which are among the biological supplements, supports intestinal health and enhances the systemic immune response (Kumar *et al.,* 2020; González-Palacios *et al.,* 2020). Lactobacillus and Bacillus species, in particular, may be beneficial in preventing fungal infections because they play a role in digestion and activate immune cells (Ali *et al.,* 2019). Some studies have reported a 40–60% reduction in fungal infection rates in fish groups supplemented with probiotics (Srivastava *et al.,* 2023).

Plant-based preventive practices are also a prominent strategy in sustainable aquaculture. In particular, low-dose feed additives containing natural products such as thyme oil, garlic extract, neem (*Azadirachta indica*), and green tea polyphenols reduce the risk of fungal infections and positively impact fish performance (Liu *et al.,* 2016; Rocchi *et al.,* 2017). These products leave no environmental residue and do not cause off-flavors in fish meat, providing advantages in terms of consumer safety (González-Palacios *et al.,* 2020).

From a sustainability perspective, integrated multi-trophic aquaculture (IMTA) systems offer significant opportunities for fungal disease prevention and system balance. In these systems, mussels, algae, or aquatic plants that filter the water are used in conjunction with fish production to balance the organic load and maintain water quality (Heikkinen *et al.,* 2013; Greco *et al.,* 2015). Minimizing organic matter and waste eliminates the environment conducive to fungal spore growth (Srivastava *et al.,* 2023).

Education and awareness are also essential for the successful implementation of preventive practices. Early intervention is possible when producers recognize the symptoms of fungal diseases, learn to monitor water quality, and implement hygiene procedures (González-Palacios *et al.,* 2020). Furthermore, regular inspections, raising employee awareness through educational materials, and instilling record-keeping habits systematize disease management (Ali *et al.,* 2019).

Consequently, a sustainable, environmentally friendly, and systematic approach is necessary for preventing fungal diseases in trout production. Water quality management, biosecurity, nutrition, probiotic use, stress reduction, and education, when implemented together, not only reduce fungal infections but also increase production efficiency and product quality (Kumar *et al.,* 2020; Srivastava *et al.,* 2023). In this context, it is important for producers to view preventive health management as a long-term profit tool rather than a cost item (Rocchi *et al.,* 2017; Liu *et al.,* 2016).

6. CONCLUSION AND RECOMMENDATIONS

Trout production is of great importance globally, both economically and in terms of food security. However, factors such as intensive production conditions, environmental stressors, and biosecurity deficiencies facilitate the emergence of fungal diseases. Many aquatic fungi, especially Saprolegnia species, cause serious losses in both hatcheries and grow-out facilities (Ali *et al.,* 2019; Srivastava *et al.,* 2023). This negatively impacts not only production volume but also product quality and farm sustainability.

As detailed in previous sections of this article, numerous variables play a role in the pathogenesis of fungal diseases, including water quality, fish immune status, and environmental management (Liu *et al.,* 2016; Rocchi *et al.,* 2017). Therefore, focusing solely on chemical treatments is not sufficient to combat these diseases. On the contrary, an integrated disease management approach based on prevention should be adopted, and treatment should only be considered as a last resort (González-Palacios *et al.,* 2020).

Chemical treatments, particularly agents such as formalin, malachite green, and hydrogen peroxide, can yield effective results. However, the environmental impacts of these substances, the risk of residue formation, and the bans on their use in some countries have necessitated a shift towards alternative strategies (Van West, 2006; Kumar *et al.,* 2020). Therefore, innovative methods such as immunostimulants, natural products, probiotics, and nanotechnology are now at the forefront in combating fungal diseases (Ali *et al.,* 2019; Srivastava *et al.,* 2023). In particular, feed additives that support the immune system and system improvements that balance water quality provide a significant increase in both disease prevention and overall production performance (Liu *et al.,* 2016).

However, biosecurity practices need to be expanded in production systems. Practices such as tank and equipment disinfection, employee hygiene, control of system inlets and outlets, and rapid removal of dead fish are critical for limiting the spread of fungal pathogens (Rocchi *et al.,* 2017; Doğan, 2024). However, for these practices to be effective, they must be implemented systematically and consistently. Field studies in Turkey have determined that fungal infection rates have significantly decreased in enterprises that regularly adhere to biosecurity practices (González-Palacios *et al.,* 2020).

Based on the results of the article, the following recommendations serve as a basic roadmap for reducing fungal diseases and ensuring sustainability in trout production:

6.1. Continuous Monitoring and Control of Water Quality

- Dissolved oxygen, ammonia, nitrite, pH, and temperature values should be monitored daily.
- Techniques such as mechanical filters, UV systems, and, when necessary, ozonization should be used to prevent organic matter accumulation (Ali *et al.,* 2019; Kumar *et al.,* 2020).

6.2. Reducing Stress Factors

- Stocking density should be adjusted appropriately for the fish species and age.
- Processes such as fish transportation, classification, and vaccination should be carried out as stress-free as possible, and post-treatment procedures should be supplemented with immune-supporting supplements (Srivastava *et al.,* 2023; Doğan, 2024).

6.3. Supporting the Immune System

- Immune-supporting substances such as vitamins C, E, and D, selenium, and zinc should be included in feeds.
- Feed additives containing beta-glucan, mannan-oligosaccharide, and probiotics should be applied at regular intervals (Liu *et al.,* 2016; Rocchi *et al.,* 2017).

6.4. Natural and Alternative Products Should Be Encouraged

- Antifungal herbal products such as thyme oil, garlic extract, neem, and green tea polyphenols should be researched and applied as feed additives at rational doses (González-Palacios *et al.,* 2020).
- Furthermore, the effects of these products on fish meat, their residue-releasing potential, and their effects on sensory characteristics should be investigated, and their commercial use should be encouraged (Ali *et al.,* 2019).

6.5. Training and Inspection Systems Should Be Improved

- Regular training programs on disease diagnosis, biosafety seminars, and water quality management should be organized for producers (Srivastava *et al.,* 2023).
- Inspection mechanisms should be strengthened and compliance with biosafety and health management practices should be encouraged (Kumar *et al.,* 2020).

6.6. Research Should Be Encouraged and International Collaboration Should Be Developed

- University-private sector collaborations should be increased to develop new antifungal agents, accelerate vaccine studies, and integrate molecular diagnostic techniques into field applications.
- Environmentally friendly and residue-free treatment alternatives should be developed, particularly in line with sustainable aquaculture goals (Rocchi *et al.,* 2017).

Consequently, combating fungal diseases should be carried out with a multifaceted, science-based approach. Currently, treatments focused solely on treatment are not providing sufficient results, so holistic health management systems should be established by analyzing the causes of diseases (Ali *et al.,* 2019; Srivastava *et al.,* 2023; Doğan, 2024). Establishing such integrated systems in developing countries like Turkey will both increase production efficiency and provide a significant advantage in international market competition. In this context, sectoral awareness and public-private partnerships are of vital importance.

REFERENCES

- Action, S. I. (2020). World fisheries and aquaculture. *Food and Agriculture Organization*, *2020*, 1-244.
- Ali, S. E., Gamil, A. A., Skaar, I., Evensen, Ø., & Charo-Karisa, H. (2019). Efficacy and safety of boric acid as a preventive treatment against Saprolegnia infection in Nile tilapia (Oreochromis niloticus). Scientific reports, 9(1), 18013.
- Anokhina, E. P., Tolkacheva, A. A., Pryakhina, N. A., Syromyatnikov, M. Y., & Korneeva, O. S. (2023). Isolation and identification of Saprolegnia spp. from infected sturgeon caviar. Acta Biologica Sibirica, 9, 13-21.
- Arslan, M. Ö., Yılmaz, M., & Taşçı, G. T. (2015). Infections of Ligula intestinalis on freshwater fish in Kars plateau of north-eastern Anatolia, Turkey. Turkiye Parazitol Derg, 39(39), 218-221.
- Buchmann, K. (2022). Control of parasitic diseases in aquaculture. *Parasitology*, *149*(14), 1985-1997.
- Doğan, M. (2024). Chemicals and Amounts Used Against Fungal Infections During Trout (Oncorhynchus mykiss) Egg Incubation Period. *Journal of Limnology and Freshwater Fisheries Research 10(3): 187-193*.
- González-Palacios, C., Fregeneda-Grandes, J. M., & Aller-Gancedo, J. M. (2020). Possible mechanisms of action of two Pseudomonas fluorescens isolates as probiotics on saprolegniosis control in rainbow trout (Oncorhynchus mykiss Walbaum). Animals, 10(9), 1507.
- Greco, M., Pardo, A., & Pose, G. (2015). Mycotoxigenic fungi and natural co-occurrence of mycotoxins in rainbow trout (Oncorhynchus mykiss) feeds. Toxins, 7(11), 4595-4609.
- Heikkinen, J., Mustonen, S. M., Eskelinen, P., Sundberg, L. R., & Von Wright, A. (2013). Prevention of fungal infestation of rainbow trout (Oncorhynchus mykiss) eggs using UV irradiation of the hatching water. Aquacultural engineering, 55, 9-15.
- Iqbal, Z., & Khatoon, Z. (2019). Fungal infection in commercially important fishes of Balloki Headworks, River Ravi, Punjab, Pakistan. Int. J. Biol. Res, 7(1), 47-55.
- Jones, E. G., Hyde, K. D., & Pang, K. L. (Eds.). (2014). Freshwater fungi: and fungal-like organisms. Walter de Gruyter GmbH & Co KG.
- Khan, S. K., Dutta, J., Rather, M. A., Ahmad, I., Nazir, J., Shah, S., Garg, A., Imam, F., Kumar, A. (2025). Assessing the Combined Toxicity of Silver and Copper Nanoparticles in Rainbow Trout (Oncorhynchus mykiss) Fingerlings. Biological Trace Element Research, 1-19.
- Kumar, S., Mandal, R. S., Bulone, V., & Srivastava, V. (2020). Identification of growth inhibitors of the fish pathogen Saprolegnia parasitica using in silico subtractive proteomics, computational modeling, and biochemical validation. Frontiers in microbiology, 11, 571093.
- Lieke, T., Meinelt, T., Hoseinifar, S. H., Pan, B., Straus, D. L., & Steinberg, C. E. (2020). Sustainable aquaculture requires environmental-friendly treatment strategies for fish diseases. Reviews in Aquaculture, 12(2), 943-965.
- Lindholm-Lehto, P. C., & Pylkkö, P. (2024). Saprolegniosis in aquaculture and how to control it?. Aquaculture, Fish and Fisheries, 4(4), e2200.
- Liu, Y., Zachow, C., Raaijmakers, J. M., & De Bruijn, I. (2016). Elucidating the diversity of aquatic Microdochium and Trichoderma species and their activity against the fish pathogen Saprolegnia diclina. International Journal of Molecular Sciences, 17(1), 140.
- Mostafa, A. A. F., Al-Askar, A. A., Dawoud, T. M., Ameen, F., & Yassin, M. T. (2020). In vitro evaluation of antifungal activity of some agricultural fungicides against two saprolegnoid fungi infecting cultured fish. Journal of King Saud University-Science, 32(7), 3091-3096.
- Najafipoor, A. (2011). Freshwater fungi isolated from eggs and broodstocks with an emphasis on Saprolegnia in rainbow trout farms in west Iran. *African Journal of Microbiology Research*, *4*(22), 3647-3651.
- Newman, S. G. (2021). Disinfectant use in Aquaculture, an Underappreciated Element of Biosecurity?. In The Shrimp Book II (pp. 562-576). GB: CABI.
- Nissa, K., Kaur, H., Ghai, N., & Katoch, A. (2024). Molecular and phylogenetic characterization of a Cnidarian parasite (Cnidaria: Myxozoa) Thelohanellus bifurcata, infecting gills of Indian major carp, Labeo rohita. Journal of Parasitic Diseases, 48(4), 767-774.
- Noga, E. J. (2010). Fish disease: diagnosis and treatment. John Wiley & Sons.
- Oono, H., Hatai, K., Miura, M., Tuchida, N., & Kiryu, T. (2007). The use of bronopol to control fungal infection in rainbow trout eggs. Biocontrol science, 12(2), 55-57.
- Özcan, F., & Arserim, N. B. (2022). Fungal diseases in fish. Black Sea Journal of Agriculture, 5(1), 48-52.
- Özdemir, R. C., Taştan, Y., & Güney, K. (2022). Prevention of Saprolegniasis in rainbow trout (Oncorhynchus mykiss) eggs using oregano (Origanum onites) and laurel (Laurus nobilis) essential oils. Journal of Fish Diseases, 45(1), 51-58.
- Qadir, M. S., Salem, H. S., Jalal, T. K., & Mohammed, S. M. (2024, December). Aquatic Fungi and Fungal Diseases of Fish: A Review. In Proceedings of the Zoological Society (Vol. 77, No. 4, pp. 430-442). New Delhi: Springer India.

- Rahman, M. A., Rahman, M. H., Yeasmin, S. M., Asif, A. A., & Mridha, D. (2017). Identification of causative agent for fungal infection and effect of disinfectants on hatching and survival rate of Bata (Labeo. Bata) larvae. Adv. Plants Agric. Res, 7, 00264.
- Refai, M. K., Marouf, S., Abuelala, N., & El-Ahl, R. H. S. (2016). Monograph on fungal diseases of fish. A guide for postgraduate students. Part, 1.
- Rocchi, S., Tisserant, M., Valot, B., Laboissière, A., Frossard, V., & Reboux, G. (2017). Quantification of Saprolegnia parasitica in river water using real-time quantitative PCR: from massive fish mortality to tap drinking water. *International Journal of Environmental Health Research*, *27*(1), 1-10.
- Russell Danner, G., & Merrill, P. (2005). Disinfectants, disinfection, and biosecurity in aquaculture. Aquaculture biosecurity: prevention, control, and eradication of aquatic animal disease, 91-128.
- Sarkar, P., Raju, V. S., Kuppusamy, G., Rahman, M. A., Elumalai, P., Harikrishnan, R., ... & Arockiaraj, J. (2022). Pathogenic fungi affecting fishes through their virulence molecules. Aquaculture, 548, 737553.
- Sharma, P., Yadav, M., Srivastava, S. K., & Singh, S. P. (2023). Bioremediation of androgenic and mutagenic pollutants from industrial wastewater. In Current Developments in Biotechnology and Bioengineering (pp. 127-138). Elsevier.
- Srivastava, A., Kumari, U., Mittal, S., & Mittal, A. K. (2023). Immunoprotective role of aloin and disease resistance in Labeo rohita, infected with bacterial fish pathogen, Aeromonas hydrophila. Environmental Science and Pollution Research, 30(11), 30062-30072.
- Tomczyk, Ł., Stępień, Ł., Urbaniak, M., Szablewski, T., Cegielska-Radziejewska, R., & Stuper-Szablewska, K. (2018). Characterisation of the mycobiota on the shell surface of table eggs acquired from different egg-laying hen breeding systems. Toxins, 10(7), 293.
- Van West, P. (2006). Saprolegnia parasitica, an oomycete pathogen with a fishy appetite: new challenges for an old problem. Mycologist, 20(3), 99-104.
- Xu, P., Ding, L., Wei, J., Li, Q., Gui, M., He, X., Su, D., He, S., & Jin, H. (2020). A new aquatic pathogen inhibitor produced by the marine fungus Aspergillus sp. LS116. Aquaculture, 520, 734670.
- Yanong, R. P. (2003). Fungal diseases of fish. Veterinary Clinics: Exotic Animal Practice, 6(2), 377-400.
- Yeasmin, S. M., Rahman, M. A., Hossain, M. M. M., Rahman, M. H., & Al Asif, A. (2015). Identification of causative agent for fungal infection and effect of disinfectants on hatching and survival rate of common carp (C. carpio) larvae. *Asian Journal of Medical and Biological Research*, *1*(3), 578-588.