Acta Aquatica Turcica

E-ISSN: 2651-5474
Home Page: https://dergipark.org.tr/actaquatr 20(3): 256-266, 2024 DOI: 10.22392/actaquatr.1363489

Review Derleme

Fungus Infections in Fish

Balıklarda Görülen Mantar Enfeksiyonları

Volkan Kaydu[1,]* , **Banu Yardımcı**[1]

[1]Ondokuz Mayıs University, Faculty of Veterinary Medicine, Department of Aquatic Animal Diseases, Samsun-TÜRKİYE

*Corresponding author: volkankaydu@gmail.com

Received: 20.09.2023 **Accepted:** 04.01.2024 **Published:** 01.09.2024

How to Cite: Kaydu, V., & Yardımcı, B. (2024). Fungus infections in fish. *Acta Aquatica Turcica, 20*(3), 256-266. https://doi.org/10.22392/actaquatr.1363489

Abstract: Many factors such as bacteria, viruses, parasites and fungi can cause infections in fish. Fungal infections are often overlooked because they are secondary to other infections. However, these infections can cause serious economic losses as they cause problems such as mortality, growth retardation, deformed appearance due to lesions on the skin, and negatively affect hatching rates, especially in farmed fish. In addition, it can cause infections in aquarium fish and the same findings can be seen in them. This article reviews the classification, aetiology, epidemiology, clinical and pathological findings, possible diagnosis, treatment and prevention of fungal infections in fish.

Keywords
- Oomycetes
- Chytridiomycetes
- Zygomycetes
- Deuteromycotina

Özet: Bakteri, virüs, parazit ve mantar gibi birçok etken balıklarda enfeksiyonlara neden olabilmektedir. Mantar enfeksiyonları, genellikle diğer enfeksiyonları takiben sekonder olarak ortaya çıktığı için gözden kaçabilmektedir. Ancak bu enfeksiyonlar özellikle yetiştiriciliği yapılan balıklarda ölüm, gelişme geriliği, deride meydana gelen lezyonlara bağlı dış görünümde deformasyonlar gibi sorunlara yol açması ve yumurtadan çıkış oranlarını da olumsuz yönde etkilemesinden dolayı ciddi ekonomik kayıplara neden olabilmektedir. Bunların yanı sıra akvaryum balıklarında da enfeksiyonlara neden olabilmekte ve aynı bulgulara onlarda da karşılaşılabilmektedir. Bu makalede balıklarda görülen mantar enfeksiyonları sınıflandırılmış, etiyoloji, epidemiyoloji, klinik ve patolojik bulguları ile olası tanı, tedavi ve koruma yöntemleri derlenmiştir.

Anahtar kelimeler
- Oomycetes
- Chytridiomycetes
- Zygomycetes
- Deuteromycotina

1. INTRODUCTION

In underdeveloped or developing countries such as Türkiye, changes in nutrition and consumption habits are inevitable depending on financial resources and herbal products are used instead of relatively expensive animal products. On the other hand, in developed countries, animal protein consumption is higher than vegetable protein consumption. To increase animal protein production in Türkiye, abundant water resources and fish production in these water resources are important (Sarıözkan, 2016).

Fungal diseases cause the highest economic losses in aquaculture after bacterial diseases (Ramaiah, 2006). Mortality rate of incubated eggs due to fungal infection can reach 80-100% (Chukanhom & Hatai, 2004). Siddique et al. (2009) examined a total of 2097 fish samples of 300 species in Bangladesh for the presence of fungal infections and found that 13.40% of cultured fish and 15.19% of wild fish were infected.

Aquatic animals, like other vertebrates, are susceptible to various pathogenic organisms, which encompass fungi (Khoo, 2000). However, the first fungal infection among vertebrates was reported as saprolegniasis in roach (*Rutilus rutilus*) in 1748 (Ainsworth, 2002).

Fungal infections in fish usually occur as secondary infections due to factors such as water quality problems (low pH, temperature, water contaminated organic matter), poor condition, trauma, high stock density, poor nutritional status, stress, dead fish, bacterial diseases and parasite infestations. However, fungal pathogens of high pathogenicity can also be the primary cause of disease. Fungal infections can be divided into external and internal (systemic) fungal infections. It has been observed that external fungal agents infect fertilized eggs and cause larval deaths and economic losses. Some fungal species are also known to proliferate in poorly stored feed, produce mycotoxins and cause toxicity (Yanong, 2003; Patel et al., 2018; Sarkar et al., 2022).

The aim of this study was to compile the information on fungal infections in fish and to contribute to the literature in this field.

2. FUNGI AND FUNGAL INFECTIONS

A vast majority of fungal organisms exhibit eukaryotic characteristics and exist as multicellular entities. They possess filamentous structures known as hyphae, which exhibit apical growth from their tips and rely entirely on heterotrophic nutrition. Most fungal species reproduce sexually and asexually via spores (Yanong, 2003). Fungi are categorized according to their life cycle, the structure of their hyphae, their reproductive components, and the spores they generate. These organisms lack the capacity to synthesize their own sustenance and can be categorized as either saprophytes, relying on deceased organic material, or parasites, which infect living organisms to obtain nutrients. It is worth noting that the majority of fungi exhibit a facultative parasitic or saprophytic lifestyle rather than an obligate one (Khoo, 2000). Hyphae play a pivotal role in enabling the expansive expansion of saprophytic and pathogenic organisms, aiding in the extensive transport within symbiotic mycorrhizal fungi, and serving as the foundational framework for the formation of multicellular reproductive structures through their aggregation (Howard & Gow, 2007).

There are three classes in the taxonomic classification of fungal pathogens. These are the classes Oomycetes, Chytridiomycetes and Zygomycetes. Species in the class Oomycetes produce motile bicellular spores. Asexual reproduction occurs through zoospores produced in the zoosporangium and this plays an important role in spread. Sexual reproduction, which occurs by fusion of two gametes to form oospores, gives its name to the class Oomycetes. Hyphae of the species in the Oomycetes class are aseptate (Roberts, 2012). Chytridiomycetes and Zygomycetes cells are coenocytic and there is no distinction between individual cells, filaments are long and tubular, the cytoplasm is lined and there is a large vacuole in the center. In the class Chytridiomycetes these unicellular organisms have hyphae branching into rhizoids and produce flagellated gametes. In the class Zygomycetes these organisms have branched mycelium and produce thick-walled spores in round spore cases called zygospores. They can reproduce sexually or asexually (McConnaughey, 2007). In addition to these, the classification also includes the Deuteromycotina (*Fungi imperfecti*) group, which consists of fungal species that share the characteristic of lacking a sexual phase. Although there are different studies conducted so far in the classification of fungal agents, the classification made by Roberts (2012) is valid. According to this classification; Saprolegnia, Achlya, Aphanomyces and Branchiomyces genera are included in Oomycetes class; Dermocystidium genus is included in Chytridiomycetes class; Ichthyophonus and Basidiobolus genera are included in Zygomycetes class (Roberts, 2012).

2.1. Oomycetes

Oomycetes are commonly known as water moulds. As such, they are multicellular and absorb nutrients through extracellular digestion. Oomycetes can infect all freshwater fish in the world. Therefore, they are thought to be primarily responsible for the decline of natural populations of salmonids and other freshwater fish. Oomycetes are classic saprophytic opportunists that growing in physically injured, stressed or infected fish. They are usually secondary pathogens resulting from bacterial infections, parasitic infestations, immunosuppression and poor husbandry conditions. However, there are also reports of oomycetes as primary pathogens (Woo et al., 2006). Stueland et al. (2005) stated that Saprolegnia species are the primary cause of disease in Atlantic salmon (*Salmo* *salar* L.) and revealed their morphological and physiological characteristics. On the other hand, Yardımcı and Turgay (2020) reported *Saprolegnia sp*. and *Aeromonas sobria* as coinfection in rainbow trout fingerlings (*Oncorhynchus mykiss*).

The taxonomic classification of oomycetes involves three distinct subclasses, namely Saprolegniomycetidae, Hypidiomycetidae, and Peronosporomycetidae. It is noteworthy that the majority of fish-pathogenic oomycetes belong to the subclass Saprolegniomycetidae.This subclass includes the orders Saprolegniales and Leptomitales (Roberts, 2012).

2.1.1. Saprolegniales and Saprolegniaceae

Saprolegnia, *Achlya* and *Aphanomyces* are the major genera in the family Saprolegniales. The taxonomy of the members of this family is complex, but the relationships between them are becoming clearer with the use of molecular methods. Saprolegniaceae are water moulds with numerous branching mycelia that look like cotton wool tufts in water (Roberts, 2012).

2.1.1.1. Saprolegniasis

Saprolegniasis stands as the prevalent and economically significant fungal ailment. Alternatively termed winter fungus or winter kill syndrome, this condition is instigated by organisms belonging to the Saprolegnia genus within the Oomycete family. Saprolegnia is known to have about 14 genera and 126 to 146 species. The most common species are reported to be *Saprolegnia parasitica* and *Saprolegnia invaderis* (Özcan & Arserim, 2022).

Saprolegniasis occurs when water temperatures drop below 15°C, especially when the water temperature drops rapidly due to cold air. The disease can be caused by immunosuppression due to rapid temperature drop, high ammonia levels in the water and stress. Morbidity and mortality increase with the amount of skin and gill tissue affected. In acute infections, fish usually die within a few days or recover within a few weeks (Noga, 2010).

Clinically, the skin shows lesions consisting of grey-white foci caused by fungal spores and cotton-like structures extending outwards from the body. Tissue necrosis occurs as the fungal mycelia grow not only outside the skin but also into the subcutaneous and muscle layers. In some cases, the starting point of infection is the digestive system. In these infections, the hyphae that develop in the stomach grow outwards by penetrating the stomach wall, muscle layer and skin. In such cases, lesions with mycelia are seen in the ventral region of the fish (Öge & Öge, 2020).

Histopathological examination of salmonids infected with *Saprolegnia spp*. during the initial phases of infection shows degenerative changes in the epidermis and dermis. In more advanced cases, deep myofibrillar and focal cellular necrosis, spongiosis, acute cellular swelling and eventual sloughing of the epidermis may be observed. The pathogen may spread from the focus of infection, destroying more of the epidermis, and hyphae may penetrate the basement membrane. Sometimes growth may continue into the hypodermis and muscles, and hyphae may penetrate blood vessels, causing thrombosis (Bruno et al., 2011).

Various techniques can be used to identify Saprolegnia species. General identification can be made by microscopic examination of asexual sporangia and zoospore shedding. Species identification is made by examination of sexual structures, oogonia, oospores and antheridia. As many isolates do not form sexual structures in vitro and information on them is inadequate, identification to species level is often difficult or impossible. This has led to the development of molecular identification methods that provide new insights into oomycete classification (Lone & Manohar, 2018). The most frequently employed technique for identification is the sequencing of the internal transcribed spacer (ITS) region. This contains the highly conserved region 18S and 28S rDNA sequence. It is approximately 700 bp long in Saprolegnia species and is considered very suitable for intraspecific analysis (Van Den Berg et al., 2013).

In 2002, following the worldwide ban on the use of malachite green in animals for human consumption due to its carcinogenic and toxic effects, research was conducted to find new treatment methods. Currently, there are several alternative treatments used in fish farms to treat Saprolegnia in eggs and fish (Barde et al., 2020). Gormez and Diler (2014) evaluated the chemical composition and antifungal activity of three Lamiaceae species, black tyme (*Thymbra spicata* L.), oregano (*Origanum onites* L.) and savory (*Satureja tymbra* L.) essential oils against *Saprolegnia parasitica* and showed positive results. In another study, Metin et al. (2015) evaluated the chemical composition and antifungal properties (in vitro and in vivo) of thyme (*Satureja cuneifolia*) essential oils obtained from the Mediterranean region of Türkiye against *Saprolegnia parasitica* strains isolated from rainbow trout (*Oncorhynchus mykiss*) eggs for the first time and positive results were obtained. The best known products for treatment purposes are bronopol, formalin, hydrogen peroxide and iodine-free salt (Barde et al., 2020).

2.1.1.2. *Achlya spp.*

Within freshwater ecosystems, the genus Achlya, a regular constituent of the fungal population, is situated within the Saprolegniaceae family. Incidences of Achlya species are frequently documented in association with fish and fish eggs. Achlya infections usually occur as secondary infections due to mechanical injury to fish or non-fungal infections (Kitancharoen et al., 1995).

Infected fish show clinical signs of fungal infection with deformed dorsal fins, darkening of colour, skin erosion and formation of a yellowish-brown cottony mass on the skin of the caudal peduncle. In some areas the scales are exfoliated and the muscles are exposed due to these lesions. These symptoms indicate chronic infection (Peyghan et al., 2019). In infected fish, the disease is characterised by surface swimming and stagnation (Khulbe et al., 1994).

Histopathological examination of the skin shows varying degrees of erosion and ulceration in the dermis and hypodermis. Epidermal and dermal cells show vacuolar degeneration and focal necrosis, focal aggregation of melanomacrophage cells in the dermis and hypodermis, and necrosis containing fragments of fungal hyphae. Muscle fibrils exhibit distinct features, including vacuolation, granulomatous inflammation, necrotic tissue, and the infiltration of inflammatory cells. Furthermore, variable-length fungal hyphae are discernible within the muscle tissue (Chauhan et al., 2013).

2.1.1.3. *Aphanomyces spp.*

Aphanomyces invadans, the only truly clonal species of Aphanomyces, is the causative agent responsible for the most significant fish outbreaks of modern times. It receives reinforcement from secondary pathogens, which encompass other oomycetes, fungi, bacteria, and parasites (Roberts, 2012). Epizootic ulcerative syndrome (EUS) is a disease that affects both wild and farmed fish in freshwater and estuarine environments (Oidtmann, 2012). Its initial description dates back to the year 1971 in Japan (Egusa & Masuda, 1971). In various geographical regions, EUS is recognized under different aliases. For instance, it goes by the name red spot disease (RSD) in Australia (Callinan et al., 1989), mycotic granulomatosis (MG) in Japan (Hatai et al., 1977), and ulcerative mycosis (UM) in the USA (Noga & Dykstra, 1986).

Aphanomyces invadans infections in fish begin with the attachment of motile zoospores to the skin surface. These organisms produce germ tubes that invade the damaged skin, with their hyphae delving deeply into the subcutaneous tissue, causing extensive ulceration and tissue damage (OIE & OIE, 2009).

In the early stages, lesions typically present as haemorrhagic bullae accompanied by small ulcerated areas along the lateral surface. Fish with mild infections show mild inflammation with petechial haemorrhages on the body, mouth, anal fin and exophthalmos in the eyes. In severe cases, deep ulcers with enlarged haemorrhagic areas, widespread inflammation and myotome necrosis may be seen. These ulcers initially appear as whitish patches with central reddish areas on the fish's skin, eventually turning into completely red areas. As the disease progresses, the severity of the exophthalmos increases, the body disintegrates and in some cases the head skin necroses (Iberahim et al., 2018). The precise reason for mortality remains elusive, although infection results in a considerable decline in blood hemoglobin and serum protein levels. In the presence of open lesions, opportunistic bacterial infections swiftly emerge and frequently serve as the ultimate factor contributing to fatality (Arshad & Arockiaraj, 2020).

From a histopathological perspective, *A. invadans* infection is distinguished by severe necrosis of the muscle tissue surrounding the invasive hyphae, eventually progressing into well-defined granulomas. Smaller non-invasive hyphae are often observed on the surface of the infection site. Hyphae in the process of migration are evident within the fascial layers and myofibrils, accompanied by myconecrosis. In instances of severe lesions, a significant influx of inflammatory cells is noted, leading to gill lamellae oedema and hyperplasia (Iberahim et al., 2018).

The use of wet mount, smear, electron microscopy or cytopathology is not sufficient to diagnose of *A. invadans* infection. Diagnosing *A. invadans* can be accomplished through histopathological examination, oomycete isolation, or the utilization of polymerase chain reaction (PCR). Determination of the growth rate, pathogenicity and sporangia morphology of the agent isolated from infected tissue is a more appropriate and more accurate method for species identification of *A. invadans*. The disadvantage of isolation is that it is time consuming and not always successful (Arshad & Arockiaraj, 2020).

EUS infection is transmitted horizontally between susceptible fish at an alarming rate. Following an outbreak in a river or canal, the pathogen is transported by EUS-infected fish to various locations downstream as the water courses along its path. At present, no efficient treatment method exists, but there are preventive measures that can be implemented to manage the dissemination of EUS. Of these, the most important precaution is to prevent infected river water from coming into contact with aquaculture farms. Adhering to quarantine procedures and health certificate requirements when transporting live fish across international borders is the primary approach for managing EUS (Lilley et al., 1998).

Within the genus Aphanomyces, there is also *Aphanomyces astaci*, which causes "crayfish plague", a disease characterised by mortality and growth retardation in Eurasian freshwater crayfish (Martin-Torrijos et al., 2023). In addition to freshwater crayfish, the Chinese mitten crab (*Eriocheir sinensis*), which also lives in freshwater, is a vector of crayfish plague and plays a role in the spread of the disease (Schrimpf et al., 2014).

2.1.1.4. *Branchiomyces spp.*

It is commonly accepted that there exist two species of Branchiomyces, both recognized solely as fungal agents affecting fish gill tissue. Among these two species, *Branchiomyces sanguinis* specifically inhabits the gill blood vessels, while *Branchiomyces demigrans* traverses the gill tissues to reach the surface (Roberts, 2012). *B. sanguinis* and *B. demigrans* species can be distinguished by differences in hyphae and spore diameter and their location in fish gills (Goodwin, 2012).

Branchiomycosis is found in carp, koi, eels, perch and many freshwater fish species and has a high mortality rate. It is an acute infection that can cause respiratory distress in fish. In aquaculture ponds, water temperature, organic matter content and high ammonia levels are the main critical factors affecting the course of the disease (Özcan & Arserim. 2022).

Branchiomycosis pathogens are transmitted horizontally between fish. Fungal spores in the water adhere to gill tissue, germinate and produce hyphae that penetrate the gill epithelium and blood vessels (Smith, 2019).

Tissues affected by branchiomycosis lose their bright red color due to circulation disorder. Necrotic tissue sloughs off, often leaving large areas where the gill arches are exposed. Infected fish are often immobile, show signs of anorexia, lose their balance and die (Meyer & Robinson, 1973).

Histologically, in fish afflicted with branchiomycosis, there is an observable hyperplasia of the lamellar epithelium, leading to the subsequent fusion of the gill lamellae. Vascular necrosis and, as a result, extensive tissue necrosis areas are seen as the fungal hyphae create thrombosis within the vessels. *B. demigrans* exhibits extensive proliferation beyond the vessel wall, forming a cluster of hyphae that infiltrate the necrotic tissue, while *B. sanguinis* does not display robust proliferation outside the blood vessels. Within 2 days of disease onset, up to 50% of the population may be infected with Branchiomyces organisms (Roberts, 2012).

Branchiomycosis can be diagnosed by wet mount or histopathological examination of infected tissue. Hyphae primarily infect the proximal gill lamellae, but if the crown of the gill is also affected, it can be examined for diagnostic purposes. Characteristic hyphae causing deep gill infection appear as diagnostic lesions (Noga, 2010).

There is no known treatment, but it is recommended to reduce the concentration of organic matter in the water and to reduce the water temperature below 20°C (Noga, 2010). Effective management is intricately associated with the quality of the water. Draining of ponds/drying of earthen ponds and liming of the pond are also recommended as control measures (Yanong, 2003).

2.2. Chytridiomycetes

2.2.1. Chytridiales

2.2.1.1. Dermocystidium

The taxonomic position of Dermocystidium is uncertain. It is a genus of unicellular parasites of fish and amphibians. These organisms have been classified as protozoa or lower fungi by various researchers. *Dermocystidium spp*. are usually found in fish, especially juveniles, and rarely in amphibians. They cause infections that result in fish mortality (Zhang & Wang, 2005).

The main Dermocystidium species are *Dermocystidium koi* and *Dermocystidium cyprini* in carp, *Dermocystidium macrophagi* in rainbow trout, *Dermocystidium percae* in sea bass, *Dermocystidium salmonis* in various salmonid species (Steckert et al., 2019).

Infected salmonids are easily identified by their ascites and abnormal behaviour. These fish are immobilised on the tank bottom or swim with difficulty (McVicar & Wootten, 1980). Systemic infections in salmonids, goldfish and tilapia show dense granuloma formation (Eli et al., 2011).

Histological examination reveals macrophage infiltration, fibrosis, diffuse cell necrosis, and a prominent fungal cyst formation (Bruno, 2001). In the gills, changes such as epithelial hyperplasia and fusion of the secondary lamellae are seen (Steckert et al., 2019).

2.3. Zygomycetes

2.3.1. Entomophthorales

2.3.1.1. *Ichthyophonus hoferi*

The initial isolation of *Ichthyophonus sp.* occurred in Germany, where it was obtained from brown trout (*Salmo trutta* L., 1758) and brook trout (*Salvelinus fontinalis* Mitchill, 1815) by Hofer in 1893. Plehn and Mulsow (1911) identified the pathogen as a fungus and named it *Ichthyophonus hoferi*. *Ichthyophonus hoferi* is an obligate pathogen with a wide host spectrum including marine and freshwater fish worldwide (Franco-Sierra et al., 1997; LaDouceur et al., 2020). *I. hoferi* is an intercellular parasite and can be cultured in vitro (Spanggaard et al., 1996). *I. hoferi* infections occur in cold waters (3-20 °C) (Ganguly et al., 2016).

It is thought that the main route of transmission to carnivorous fish is the ingestion of infected fish. The mode of transmission to wild herbivorous fish is unclear. Experimentally, intraperitoneal injection of isolated fungal pathogens or feeding of feed contaminated with the pathogen resulted in the highest infection rates. There is no evidence for vertical transmission. The use of infected marine fish in the diet of farmed aquaculture fish is a source of infection (Smith, 2019).

Infected fish show stagnation, pale colour, irregular scales and extensive loss of scales on the body surface, erosions of the tail and pectoral fins. In necropsy, grayish white granular formations are observed in the internal organs, especially the heart and kidney (Öztürk et al., 2010).

In diagnosis, culture is considered the most sensitive detection technique, especially for low-intensity infections. PCR and qPCR, histology and imprint preparation are used alone or in combination with culture (Smith, 2019).

There is no known treatment. Contaminated feed should be avoided and pasteurised feed should be used. Ichthyophonus can render fillets unmarketable due to foul odour and poor muscle development. Infected fillets should be culled as infected fillets can contaminate normal fillets by contact (Noga, 2010).

2.3.1.2. Basidiobolus

The classification of Basidiobolus as a fish pathogen remains ambiguous. *Basidiobolus ranarum*, which also occurs in fish, is a fungal species regularly isolated from frog faeces. Another species, *Basidiobolus meristophorus*, has been associated with juvenile carp and their eggs (Roberts, 2012).

2.4. Deuteromycotina (*Fungi imperfecti*)

Fungi imperfecti are a group of fungal species characterised by the absence of a sexual (teleomorphic) stage. Many fish infections caused by these species have been described. Generally recognised as opportunistic pathogens, these infections are chronic, progressive and fatal when they occur. In cases of extensive infections within aquaculture, the resulting economic losses have the potential to be disastrous. A formal taxonomic system for categorizing the pathogens or infections within this unique grouping does not currently exist (Roberts, 2012).

2.4.1. Aspergillomycosis

Numerous members of the Moniliacea exhibit pathogenic characteristics, and due to the challenges associated with identifying sexual stages in many of them, this group is commonly taxonomically classified within the Deuteromycotina (*Fungi imperfecti*). The name "Aspergillus" originates from the distinctive appearance of its aspergillum, akin to holy water brushes, and its spore heads a feature recognized by the priest Micheli (1729), who bestowed this name. Aspergillus species are widely distributed and primarily participate in saprophytic decomposition processes. The formation of aflatoxins, as by-products from Aspergillus's breakdown of fish feed, is responsible for aflatoxicosis in fish (Roberts, 2012).

Clinical findings in infected fish are abdominal bloating, darkening in color and lethargy. Necropsy of infected fish shows abundant fluid in the abdominal cavity and severe focal necrosis of the liver. Mortality varies at different growth stages and can be at least 20% of the population (Roberts, 2012).

2.4.2. Systemic Mycosis of Channel Catfish

In 1969, Fijan reported a condition marked by the presence of ulcers ranging from 2 to 15 mm in diameter, with depths reaching 5 mm on the skin. This ailment exhibited both hematogenous and localized spread in channel catfish, leading to adhesions within internal organs and peritonitis. Within the nodules, tubular, branched, septate hyphae that tested positive for PAS staining were identified, leading to the conclusion that the causative agent belonged to the Dematiaceae family. Intraperitoneal injection of fungal agents caused infection in channel catfish, white catfish and bluegill. The method facilitated the isolation and subsequent re-identification of the causative agent.

2.4.3. Cerebral Mycetoma

In 1967, Carmichael reported an epizootic disease termed cerebral mycetoma in cutthroat trout, induced by a Phialophora-like fungus. This pathogen was subsequently named *Exophiala salmonis*, and the associated lesions were characterized as chronic, non-suppurative granulomas containing numerous giant cells in the brain and cranial area. Meanwhile, in 1987, Langdon and McDonald documented an *Exophiala pisciphila* infection in Atlantic salmon, which led to substantial mortality. This infection involved hyphal invasion of the head, lateral region, and semicircular canals, resulting in diffuse granulomatous inflammation accompanied by cartilaginous necrosis.

2.4.4. Systemic *Phialophora* Infection

In their research on Phialophora infection in Atlantic salmon, Ellis et al. (1983) provided an exceptionally detailed account of systemic infection. This type of infection predominantly occurs during low water temperatures, notably in January. Affected fish show an accumulation of bloody, purulent fluid in the abdominal cavity, a distended kidney and, characteristically, a deflated swim bladder with petechial haemorrhages at the base of the fins and on the surface of the abdomen. A distinctive feature includes a collapsed swim bladder adorned with petechial hemorrhages at the fin bases and on the abdominal surface. Whitish masses, comprising densely clustered mycelium, were noted on the internal organs' surfaces, and hyphae were observed within the lumen of the collapsed swim bladder.

2.4.5. *Scolecobasidium humicola* Infection

For experimental purposes, Ross and Yasutake (1973) induced a systemic infection in coho salmon. Typically, the afflicted fish display abdominal distension accompanied by skin lesions. Common observations include ascites, adhesions, and gray areas within internal organs, particularly the kidneys. In natural outbreaks, the morbidity rate is relatively low. Colonies cultivated on Sabouraud dextrose agar exhibit an olive coloration and possess a powdery surface texture.

In 1946, Doty and Slater documented a *Heterosporium* species that posed a threat to Chinook salmon. While this genus is no longer considered taxonomically distinct, Ross and Yasutake (1973) proposed its resemblance to *Scolecobasidium* and suggested that it might be another species within this genus.

2.4.6. Sphaeropsidales Infection

Ross et al. (1975) isolated *Phoma herbarum*, typically known as a common plant saprophyte, from three distinct diseased salmonid species in the states of Washington and Oregon. Earlier, Wood (1968) reported this infection in Chinook salmon in a brief study.

Phoma herbarum rarely contaminates fish feed and may cause granulomatous disease, particularly in the kidney. The morbidity rate in salmonid outbreaks rarely exceeds 5% and the disease usually affects juveniles (Roberts, 2012).

3. CONCLUSION

The increase in fish farming as a source of animal protein in recent years has led to an increase in fungal infections. Fungal diseases are the diseases that cause the most economic losses after bacterial diseases due to the lesions and deaths they cause in fish farming. Therefore, controlling fungal diseases is important for the growth of fish farming. Fungal diseases usually appear as secondary infections and therefore it is important to eliminate the primary causes (stress, stocking density, water quality problems, infectious agents, etc.) by disinfection, avoidance of contaminated feeds, quarantine and compliance with health certificate guidelines. With the ban on the use of malachite green, various treatment methods have been tried and successful results have been obtained and research is still ongoing. It is concluded that alternative methods for diagnosis, treatment and control should continue to be investigated in order to control fungal diseases.

FUNDING

No financial support was received for the present study.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR CONTRIBUTIONS

Fiction: VK, BY; Literature: VK; Manuscript writing: VK; Supervision: BY. All authors approved the final draft.

ETHICAL STATEMENTS

Local Ethics Committee Approval was not obtained because experimental animals were not used in this study.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable for the present study as no new data was created or analyzed.

REFERENCES

Ainsworth, G. C. (2002). *Introduction to the history of medical and veterinary mycology*. Cambridge University Press.

Arshad, P. E., & Arockiaraj, J. (2020). Pathogenicity and pathobiology of epizootic ulcerative syndrome (EUS) causing fungus *Aphanomyces invadans* and its immunological response in fish. *Reviews In Fisheries Science*, *28*(3), 358-375. https://doi.org/10.1080/23308249.2020.1753167

Barde, R. D., Deshpande, M., Nagthane, N., Darak, O., & Baig, M. M. V. (2020). A review of Saprolegnia infection in freshwater fishes and control of the saprolegniosis. *Sustainable Humanosphere*, *16*(1), 702-711. ISSN: 1880-6503

Bruno, D. W. (2001). *Dermocystidium sp.* in Scottish Atlantic salmon, *Salmo salar*: evidence for impact on fish in marine fish farms. *Bulletin-European Associatıon Of Fish Pathologists*, *21*(5), 209-213.

Bruno, D., VanWest, P., & Beakes, G. (2011). Saprolegnia and other oomycetes. *Fish Diseases and Disorders: Volume 3: Viral, Bacterial and Fungal Infections, 2nd Edition*. CABI.

Callinan, R. B., Fraser, G. C., & Virgona, J. L. (1989). Pathology of red spot disease in sea mullet, *Mugil cephalus* L., from eastern Australia. *Journal of Fish Diseases*, *12*(5), 467-479. https://doi.org/10.1111/j.1365-2761.1989.tb00558.x

Carmichael, J. W. (1967). Cerebral mycetoma of trout due to a Phialophora-like fungus. *Sabouraudia: Journal of Medical and Veterinary Mycology*, *5*(2), 120-123. https://doi.org/10.1080/00362176785190211

Chauhan, R., Lone, S., & Tabbsum, H. G. (2013). Mycotic studies of some freshwater fishes with emphasis on *Achlya spp*. *International Journal of Fisheries and Aquaculture*, *3*(4), 165-169. ISSN: 2277-7729

Chukanhom, K., & Hatai, K. (2004). Freshwater fungi isolated from eggs of the common carp (Cyprinus carpio) in Thailand. *Mycoscience*, *45*, 42-48. https://doi.org/10.1007/s10267-003-0153-9

Doty, M. S., & Slater, D. W. (1946). A new species of Heterosporium pathogenic on young chinook salmon. *The American Midland Naturalist*, *36*(3), 663-665. https://doi.org/10.2307/2421459

Egusa, S., & Masuda, N. (1971). A new fungal of *Plecoglossus altivelis*. *Fish Pathology*, *6*(1), 41-46. https://doi.org/10.3147/jsfp.6.41

Eli, A., Briyai, O. F., & Abowei, J. F. N. (2011). A review of some fungi infection in African fish saprolegniasis, dermal mycoses; branchiomyces infections, systemic mycoses and dermocystidium. *Asian Journal of Medical Sciences*, *3*(5), 198-205. ISSN: 2040-8773

Ellis, A. E., Waddell, I. F., & Minter, D. W. (1983). A systemic fungal disease in Atlantic salmon parr, *Salmo salar* L., caused by a species of Phialophora. *Journal of Fish Diseases*, *6*(6), 511-523. https://doi.org/10.1111/j.1365-2761.1983.tb00105.x

Fijan, N. (1969). Systemic mycosis in channel catfish. *Bulletin of the Wildlife Disease Association*, *5*(2), 109-110. https://doi.org/10.7589/0090-3558-5.2.109

Franco-Sierra, A., Sitjá-Bobadilla, A., & Alvarez-Pellitero, P. (1997). Ichthyophonus infections in cultured marine fish from Spain. *Journal of Fish Biology*, *51*(4), 830-839. https://doi.org/10.1111/j.1095-8649.1997.tb02003.x

Ganguly, S., Wakchaure, R., Praveen, P. K., & Para, P. A. (2016). Fungal infections in fishes: A brief review. *Internaltional Journal of Pharmacy & Life Sciences*, *7*(9), 5245-5246.

Goodwin, A. E. (2012). A. Etiological Agent.

Gormez, O., & Diler, O. (2014). In vitro antifungal activity of essential oils from Tymbra, Origanum, Satureja species and some pure compounds on the fish pathogenic fungus, *Saprolegnia parasitica*. *Aquaculture Research*, *45*(7), 1196-1201. https://doi.org/10.1111/are.12060

Hatai, K., Egusa, S., Takahashi, S., & Ooe, K. (1977). Study on the pathogenic fungus of mycotic granulomatosis—I Isolation and pathogenicity of the fungus from cultured-ayu infected with the disease. *Fish Pathology*, *12*(2), 129-133. https://doi.org/10.3147/jsfp.12.129

Hofer, V. B. (1893). Eine salmoniden-erkrankung. *Allgemeine Fischereizeitung*, *18*, 169-171.

Howard, R. J., & Gow, N. A. (Eds.). (2007). *Biology of the fungal cell* (Vol. 8). Springer Science & Business Media.

Iberahim, N. A., Trusch, F., & Van West, P. (2018). *Aphanomyces invadans*, the causal agent of epizootic ulcerative syndrome, is a global threat to wild and farmed fish. *Fungal Biology Reviews*, *32*(3), 118-130. https://doi.org/10.1016/j.fbr.2018.05.002

Khoo, L. (2000, April). Fungal diseases in fish. *Seminars in Avian and exotic pet medicine*, 9(2), 102-111. https://doi.org/10.1053/AX.2000.4623

Khulbe, R. D., Bisht, G. S., & Joshi, C. (1994). Epizootic infection due to *Achlya debaryana* in a catfish. *Mycoses*, *37*(1-2), 61-63. https://doi.org/10.1111/j.1439-0507.1994.tb00288.x

Kitancharoen, N., Hatai, K., Ogihara, R., & Aye, D. N. N. (1995). A new record of *Achlya klebsiana* from snakehead, *Channa striatus*, with fungal infection in Myanmar. *Mycoscience*, *36*(2), 235-238. https://doi.org/10.1007/BF02268563

LaDouceur EEB, Leger JS, Mena A, Mackenzie A, Gregg J, Purcell M, Batts W, Hershberger P. (2020). *Ichthyophonus sp.* infection in opaleye (*Girella nigricans*). *Veterinary Pathololology*, *57*(2), 316-320. https://doi.org/10.1177/0300985819900015

Langdon, J. S. (1987). Cranial *Exophiala pisciphila* infection in *Salmo salar* in Australia. *Bulletin of the European Association of Fish Pathologists*, *7*, 35-37.

Lilley, J. H., Callinan, R. B., Chinabut, S., Kanchanakhan, S., & MacRae, I. H. (1998). *Epizootic ulcerative syndrome (EUS) technical handbook.* The Aquatic Animal Research Institute, Bangkok, Thailand.

Lone, S. A., & Manohar, S. (2018). *Saprolegnia parasitica*, a lethal oomycete pathogen: demands to be controlled. *Journal of Infecion and Molecular Biology*, *6*(2), 36-44. https://doi.org/10.17582/journal.jimb/2018/6.2.36.44

Martín-Torrijos, L., Hernández-Pérez, A., Monroy-López, J. F., & Diéguez-Uribeondo, J. (2023). Aphanomyces astaci in Mexico: A new haplotype from dwarf crayfish *Cambarellus montezumae*. *Journal of Invertebrate Pathology*, *201*, 108000. https://doi.org/10.1016/j.jip.2023.108000

McConnaughey, M.B., (2007) Physical and chemical properties of fungi. In Enna, S.J., Bylund, D.B., (Eds.), In *XPharm: The Comprehensive Pharmacology Reference* (pp. 1–3). Elsevier Inc.

McVicar, A.H., Wootten, R. (1980). Disease in farmed juvenile Atlantic Salmon caused by *Dermocystidium sp.* In Ahne, W. (eds) *Fish Diseases. Proceedings in Life Sciences* (pp 165-173). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-67854-7_27

Metın, S., Dıler, O., Dıdınen, B. I., Terzıoglu, S., & Gormez, O. (2015). In vitro and in vivo antifungal activity of *Satureja cuneifolia* ten essential oil on *Saprolegnia parasitica* strains isolated from rainbow trout (*Oncorhynchus mykiss*, Walbaum) eggs. *Aquaculture Research*, *46*(6), 1396-1402. https://doi.org/10.1111/are.12293

Meyer, F. P., & Robinson, J. A. (1973). Branchiomycosis: a new fungal disease of North American fishes. *The Progressive Fish-Culturist*, *35*(2), 74-77. https://doi.org/10.1577/1548-8659(1973)35[74:BNFDON]2.0.CO;2

Micheli, P. A. (1729). *Nova plantarum genera iuxta Tournefortii methodum disposita quibus plantae 1900 recensentur, scilicet fere 1400 nondum observatae, reliquae suis sedibus restitutae; quarum vero figuram exhibere visum fuit, eae ad 550 aeneis tabulis 108 graphice expressae sunt; adnotationibus, atque observationibus, praecipue fungorum, mucorum, affiniumque plantarum sationem, ortum,[€ t] incrementum spectantibus, interdum adiectis..*. Typis Bernardi Paperinii.

Noga, E. J. (2010). *Fish disease: diagnosis and treatment*: John Wiley & Sons.

Noga, E. J., & Dykstra, M. J. (1986). Oomycete fungi associated with ulcerative mycosis in menhaden, *Brevoortia tyrannus* (Latrobe). *Journal of Fish Diseases*, *9*(1), 47-53. https://doi.org/10.1111/j.1365-2761.1986.tb00978.x

OIE, & OIE. (2009). Epizootic ulcerative syndrome. In: Office Internationale des Epizooties Paris.

Oidtmann, B. (2012). Review of biological factors relevant to import risk assessments for epizootic ulcerative syndrome (*Aphanomyces invadans*). *Transboundary and Emerging Diseases*, *59*(1), 26-39. https://doi.org/10.1111/j.1865-1682.2011.01241.x

Öge, H., & Öge, S. (2020). Mantar (mikotik) hastalıkları. In Yarsan, E. (Eds.), *Balık hekimliği* (pp. 295-306). Güneş Tıp Kitabevleri.

Özcan, F., & Arserim, N. B. (2022). Fungal diseases in fish. *Black Sea Journal of Agriculture*, *5*(1), 48-52. https://doi.org/10.47115/bsagriculture.983345

Öztürk, T., Özer, A., Taskaya, G., Öz, M., & Aral, O. (2010). Japon balığında (*Carassius auratus*) *Ichthyophonus hoferi* enfeksiyonu. *Journal of Fisheries Sciences.com*, *4*(4), 304. https://doi.org/10.3153/jfscom.2010033

Patel, A. S., Patel, S. J., Bariya, A. R., Pata, B. A., & Ghodasara, S. N. (2018). Fungal diseases of fish: A review. *Journal of Veterinary Science & Research*, *3*(3), 000164.

Peyghan, R., Rahnama, R., Tulaby Dezfuly, Z., & Shokoohmand, M. (2019). Achlya infection in an Oscar (*Astronotus ocellatus*) with typical symptoms of saprolegniosis. *Veterinary Research Forum*, 10(1), 89-92. https://doi.org/10.30466/vrf.2019.34315

Plehn, M. & Mulsow, K. (1911). Der erreger der “taumelkrankheit” der salmoniden. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene* 59, 63– 68.

Ramaiah, N. (2006). A review on fungal diseases of algae, marine fishes, shrimps and corals. *Indian Journal of Marine Sciences*, *35*(4), 380-387.

Roberts, R. J. (2012). *Fish pathology*. John Wiley & Sons.

Ross, A. J., & Yasutake, W. T. (1973). *Scolecobasidium humicola*, a fungal pathogen of fish. *Journal of the Fisheries Board of Canada*, *30*(7), 994-995. https://doi.org/10.1139/f73-161

Ross, A. J., Yasutake, W. T., & Leek, S. (1975). *Phoma herbarum*, a fungal plant saprophyte, as a fish pathogen. *Journal of the Fisheries Board of Canada*, *32*(9), 1648-1652. https://doi.org/10.1139/f75-193

Sarıözkan, S. (2016). Türkiye'de balıkçılık sektörü ve ekonomisi. *Aquatic Sciences and Engineering, 31*(1), 15-22. https://doi.org/10.18864/TJAS201602

Sarkar, P., Raju, V. S., Kuppusamy, G., Rahman, M. A., Elumalai, P., Harikrishnan, R., Arshad, A., & Arockiaraj, J. (2022). Pathogenic fungi affecting fishes through their virulence molecules. *Aquaculture*, *548*(1), 737553. https://doi.org/10.1016/j.aquaculture.2021.737553

Schrimpf, A., Schmidt, T., & Schulz, R. (2014). Invasive Chinese mitten crab (*Eriocheir sinensis*) transmits crayfish plague pathogen (*Aphanomyces astaci*). *Aquatic Invasions*, *9*(2), 203-209. http://dx.doi.org/10.3391/ai.2014.9.2.09

Siddique, M. A. B., Bashar, M. A., Hussain, M. A., & Kibria, A. S. M. (2009). Fungal disease of freshwater fishes in Natore district of Bangladesh. *Journal of the Bangladesh Agricultural University*, *7*(1), 157-162. https://doi.org/ 10.22004/ag.econ.208354

Smith, S. A. (Ed.). (2019). *Fish diseases and medicine*. CRC Press.

Spanggaard, B., Skouboe, P., Rossen, L., & Taylor, J. W. (1996). Phylogenetic relationships of the intercellular fish pathogen *Ichthyophonus hoferi* and fungi, choanoflagellates and the rosette agent. *Marine Biology*, *126*, 109-115. https://doi.org/10.1007/BF00571382

Steckert, L. D., Cardoso, L., Tancredo, K. R., Martins, M. L., & Jeronimo, G. T. (2019). *Dermocystidium sp.* in the gills of farmed *Oreochromis niloticus* in Brazil. *Anais da Academia Brasileira de Ciências*, 91(3). https://doi.org/10.1590/0001-3765201920180959

Stueland, S., Hatai, K., & Skaar, I. (2005). Morphological and physiological characteristics of *Saprolegnia spp.* strains pathogenic to Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases*, *28*(8), 445-453. https://doi.org/10.1111/j.1365-2761.2005.00635.x

Van Den Berg, A. H., McLaggan, D., Diéguez-Uribeondo, J., & Van West, P. (2013). The impact of the water moulds *Saprolegnia diclina* and *Saprolegnia parasitica* on natural ecosystems and the aquaculture industry. *Fungal Biology Reviews*, *27*(2), 33-42. https://doi.org/10.1016/j.fbr.2013.05.001

Woo, P. T., Leatherland, J. F., & Bruno, D. W. (2006). *Fish diseases and disorders* (Vol. 3). CABI.

Wood, J.W. (1968) *Diseases of Pacific salmon, their prevention and treatment.* Olympia, Washington: Department of Fisheries, Hatchery Division, State of Washington.

Yanong, R. P. (2003). Fungal diseases of fish. *Veterinary Clinics: Exotic Animal Practice*, *6*(2), 377-400. https://doi.org/10.1016/S1094-9194(03)00005-7

Yardımcı, R., & Turgay, E. (2020). Diagnosis of *Aeromonas sobria* and *Saprolegnia sp.* co-infection in rainbow trout fry (*Oncorhynchus mykiss*). *Aquatic Research*, *4*(1), 65-72. https://doi.org/10.3153/AR21006

Zhang, Q., & Wang, Z. (2005). *Dermocystidium sp.* infection in cultured juvenile southern catfish *Silurus meridionalis* in China. *Diseases of Aquatic Organisms*, *65*(3), 245-250. https://doi.org/10.3354/dao065245