

# *Streptococcal Infections in Aquaculture Systems: Pathogenesis, Genomic Insights, and Challenges in Disease Management*

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## **ABSTRACT**

Streptococcal infections are among the most destructive bacterial diseases affecting aquaculture worldwide, particularly in warm-water fish such as Nile tilapia (*Oreochromis niloticus*). Despite long-term dependence on antibiotics, streptococcosis continues to cause recurrent outbreaks, high mortality, and severe economic losses. The persistence of this disease is largely attributed to pathogen diversity, virulence variation, host-pathogen interaction, and the emergence of antibiotic-resistant strains. Recent advances in genomic and proteomic studies have provided critical insights into the adaptive mechanisms and virulence determinants of fish-pathogenic *Streptococcus* spp. This article reviews the epidemiology, pathogenesis, genomic characterization, and current challenges in the management of streptococcal infections in aquaculture systems.

## **INTRODUCTION**

**A**quaculture has grown to become one of the most rapidly growing animal production systems in the world;

however, the sustainability of this sector is increasingly being compromised by infectious diseases. In the category of bacterial diseases,

streptococcal diseases have been found to be a significant limiting factor for animal production, especially in the context of intensive culture systems for warm-water fishes. Streptococcosis is a fish disease with the following characteristics: the disease progresses very quickly, the infection is generalized, and the mortality rate is very high, even with the use of antibiotics.

The disease has been reported from all but a few fish cultured around the world, such as Asia, Africa, Europe, Australia, and the Americas. The increased incidence of failed treatment outcomes underscores an immediate need to reassess control measures currently implemented and to gain an insight into fish-pathogenic *Streptococcus* spp. at a deeper level (Abdallah *et al.*, 2024).

### **Etiological Agents of Streptococcosis**

Streptococcosis is one of the diseases responsible for infection in fish and is caused by different *Streptococcus* species; the main causative organisms include *Streptococcus agalactiae*, *Streptococcus iniae*, *Streptococcus parauberis*, and *Streptococcus dysgalactiae*. Of these organisms, *Streptococcus agal*

The genetic strains of fish-pathogenic *S. agalactiae* are different from human and bovine isolates, exhibiting strong host adaptation along with virulence traits that are advantageous for survival in aquatic environments (Tavares *et al.*, 2019).

### **Epidemiology and Risk Factors**

Streptococcal outbreaks are strongly linked with environmental and management-related risk factors. For instance, high fish density, high water temperatures, and substandard water conditions are all elements that increase the risks for fish to acquire an infection caused by streptococcus (Mishra *et al.*, 2018). For instance, the typical peak water temperature at which such streptococcal infections are likely

to result in an outbreak is usually 26 °C and above.

The epidemiological role of carrier fish is noteworthy, facilitating relapse as reservoirs of infection, even in cases where full recovery is achieved (Abdallah *et al.*, 2024).

### **Clinical Signs and Pathogenesis**

Streptococcal infections are systemic. Affected fishes usually display disease through the following clinical signs: lethargy, loss of appetite, exophthalmia, corneal opacity, hemorrhages, ascites, spiraling motions of the body, and loss of balance (Mishra *et al.*, 2018).

Pathogenesis includes the entry of bacteria through gills, skin lesions, and the gastrointestinal compartment; rapid subsequent hematogenous spread from the above compartments; and the septicemia and neurological changes, including meningoencephalitis, a hallmark of the pathologic process in the case of *S. agalactiae* infections (Abdallah *et al.*, 2024).

### **Genomic and Proteomic Insights into Fish-Pathogenic *Streptococcus* ssp.**

"Whole-genome sequencing and pan-proteomic research have completely transformed the approach taken to streptococcal pathogenicity, with comparative research revealing the high level of core genome conservation seen among *S. agalactiae* strains infecting fish and their accessory genomes involved in virulence, stress resistance, and adaptation to the host." (Tavares *et al.*, 2019)

The proteomic studies established that strains which infect fish have significantly upregulated proteins linked to metabolism, immune evasion, and environmental stress. The adaptations enable survival in aquatic systems and facilitate colonization of fish hosts (Tavares *et al.*, 2019).

Genomic research again points to the extensive occurrence of horizontal gene transfer, which is contributing to strain variability as well as the emergence of virulent strains (Tavares *et al.*, 2018).

### **Antibiotic Resistance and Treatment Failure**

Antibiotics are the most employed control measures in the management of streptococcal infections. However, the efficacy of antibiotics in the control of streptococcal infections is reduced. The overuse and misuse of antibiotics have given rise to resistant strains, resulting in treatment failure.

Most commonly used antibiotic sensitivity tests fail to predict field results because they do not take into account virulence factors; survival within the cells; nor the immune capacity of the host animal. Genomic studies have identified genes linked to resistance as reasons why antibiotics work in a laboratory setting but fail in the actual field conditions (Schar *et al.*, 2020).

### **Sustainable Control Strategies**

Effective management requires integrated approaches combining:

- Early molecular diagnosis
- Biosecurity implementation
- Stress minimization
- Environmental management
- Vaccination

Proteomics-based identification of conserved antigens provides promising vaccine candidates for long-term protection (Tavares *et al.*, 2019).

Reducing dependence on antibiotics is critical for sustainable aquaculture health management.

### **Challenges and Future Perspectives in Disease Management**

For effective management of streptococcosis, it is necessary to transition from an antibiotic-centric approach to adopt a more comprehensive health management approach. Biosecurity, reduction of stress, diagnosis, and genomic-based surveillance are some of the essential elements of sustainable management (Mishra *et al.*, 2018).

The use of proteomics to identify conserved antigens has provided a new opportunity for the development of vaccines, which can confer long-term protection against various strains of fish-pathogenic *S. agalactiae* (Tavares *et al.*, 2019). More research is thus needed in the field in the future, which can combine genomics, transcriptomics, and proteomics to provide insights into the evolution of pathogens.

### **CONCLUSION**

To effectively manage the disease of streptococcosis, it is important that the focus shift from antibiotics to more comprehensive health management. To achieve this, various steps such as biosecurity, reduction of stress levels, diagnosis, and surveillance using genomics are the key to the management of the disease (Mishra *et al.*, 2018).

The use of proteomics to identify conserved antigens has opened up a new avenue to develop vaccines that can protect fish from a wide range of fish-pathogenic *S. agalactiae* strains over the long term (Tavares *et al.*, 2019). Further research needs to be done in this field in the coming years, which may include genomics, transcriptomics, and proteomics to explore the evolutionary pattern of the pathogens.

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