



A Monthly e Magazine
ISSN:2583-2212

Popular Article

February, 2026 Vol.6(2), 403-407

Engineering the Invisible: How the Fish Gut Microbiome Is Transforming Aquaculture

Siyag Dhere¹, Swapnil Narsale¹, Rishikesh Kadam¹, Prachi Asgolkar¹, Kiran Rasal^{1*}

¹ICAR- Central Institute of Fisheries Education, Mumbai, Maharashtra

*Corresponding author:

Dr. Kiran Rasal

Senior Scientist

Fish Genetics and Biotechnology Division

ICAR- Central Institute of Fisheries Education, Mumbai, Maharashtra

Email: kiranrasal@cife.edu.in

[DOI:10.5281/ScienceWorld.18673587](https://doi.org/10.5281/ScienceWorld.18673587)

Abstract

Aquaculture is increasingly turning to the fish gut microbiome as a powerful tool for improving productivity and sustainability. This invisible community of microorganisms plays a crucial role in digestion, immunity, stress tolerance, and disease resistance. By engineering microbial balance through probiotics, prebiotics, functional feeds, and precision management strategies, farmers can enhance feed efficiency, reduce antibiotic dependence, and improve fish health. Advances in microbial research are enabling targeted interventions tailored to species and production systems. Fish gut microbiome engineering represents a transformative, eco-friendly approach to building more resilient and efficient aquaculture systems.

Keywords: Microbiome, Aquaculture, Microorganisms, Probiotics, Prebiotics

Introduction

When we think about improving fish farming, we often imagine better feeds, stronger cages, or advanced breeding technologies. But one of the most powerful tools for transforming aquaculture is invisible to the naked eye. It lives inside the fish itself, in its gut. Beneath the surface of every farmed fish lies a bustling microscopic ecosystem that quietly shapes its growth, health, and resilience. This internal community of bacteria and other microbes, collectively known as the gut microbiome, acts like a hidden partner in aquaculture production. Though invisible, these organisms influence how efficiently fish digest feed, fight disease, and respond to environmental stress. Understanding and managing this inner world could redefine how we raise fish more productively and sustainably.



The Hidden Workforce Inside Every Fish

Just like humans, fish carry complex communities of bacteria, fungi, and other microorganisms in their digestive tract (Singh *et al.*, 2025). This community, known as the gut microbiome, helps digest food, produce essential nutrients, regulate immunity, and protect against harmful pathogens.

For years, these microbes were largely ignored in aquaculture. But scientists now recognize that they act as a biological “support team,” influencing everything from feed efficiency to disease resistance.

If the microbiome is balanced, fish thrive. If it is disturbed, due to stress, poor water quality, antibiotics, or suboptimal feed, fish may become more susceptible to infections, grow slowly, or experience metabolic problems (Yang *et al.*, 2024).

The big question is: What if we could design or engineer this microbial community to work even better?

From Observation to Engineering

Traditionally, farmers used antibiotics to control disease outbreaks. However, overuse has led to antibiotic resistance, a major global concern. Today, the industry is shifting toward smarter, eco-friendly solutions. Rather than killing harmful bacteria, this approach focuses on promoting beneficial ones. It works on a simple principle: if good microbes occupy the gut, there is less space and fewer resources available for harmful pathogens.

This strategy includes:

- **Probiotics** – Adding beneficial bacteria to feed
- **Prebiotics** – Supplying nutrients that selectively nourish good microbes
- **Synbiotics** – A combination of both
- **Functional feeds** – Diets enriched with plant extracts, organic acids, or bioactive compounds that shape microbial balance

These interventions do not alter the fish’s DNA. Instead, they optimize the biological ecosystem within.

Why the Gut Microbiome Matters So Much

The fish gut microbiome influences aquaculture in several important ways:

- **Better Feed Utilization:** Feed represents the highest cost in aquaculture production. Certain gut microbes produce enzymes that help break down complex carbohydrates, proteins, and lipids (Rai *et al.*, 2025). A well-balanced microbiome can improve digestion and increase feed conversion efficiency.



- **Stronger Immunity:** The gut is one of the largest immune organs in fish. Beneficial microbes stimulate immune cells, produce antimicrobial compounds, and create physical barriers against invading pathogens
- **Reduced Need for Antibiotics:** By stabilizing microbial communities, microbiome engineering lowers the risk of infections. This helps reduce antibiotic use, protecting both aquatic ecosystems and human health.
- **Stress Tolerance:** Aquaculture environments can be stressful, with fluctuating temperatures, crowding, and handling procedures that challenge fish physiology. A stable gut microbiome supports metabolic resilience, helping fish cope with stress more effectively.



Fig 1. Importance of gut microbiome in aquaculture

The Science Behind the Scenes

Modern biotechnology tools have accelerated microbiome research. Scientists can now identify thousands of microbial species present in fish intestines using advanced sequencing techniques.

These studies reveal that:

- Different fish species host distinct microbial communities.
- Diet strongly influences microbial composition.
- Environmental conditions such as salinity and temperature reshape gut ecosystems.



Importantly, researchers are discovering “core microbiomes”, groups of microbes consistently associated with healthy fish. This knowledge allows scientists to design targeted microbial formulations instead of relying on trial and error.

Toward Precision Microbiome Management

The future of aquaculture may involve precision microbial management, where feeds are customized based on species, life stage, and environmental conditions. Imagine a hatchery using one probiotic mix for larval stages to boost survival, and another for grow-out phases to enhance feed efficiency. Or farms selecting microbial supplements based on seasonal temperature shifts.

Some researchers are even exploring:

- **Next-generation probiotics** derived from the fish’s own native microbiota
- **Microbiome transplantation**, similar to faecal transplants in human medicine
- **Bacteriophage therapy** to selectively target harmful bacteria without disrupting beneficial ones

Sustainability and the Bigger Picture

Engineering the fish gut microbiome is not just about boosting production. It also addresses larger sustainability challenges. Healthier fish require fewer chemical treatments. Improved feed conversion reduces resource use. Lower mortality rates decrease economic losses and environmental waste. In a world where seafood demand continues to rise, aquaculture must produce more with fewer ecological impacts. Microbiome engineering offers a natural, biologically aligned solution. Rather than fighting nature, it works with it.

Challenges Ahead

Despite its promise, microbiome engineering is not without challenges.

- Microbial communities are highly complex and dynamic.
- Results may vary across species and farming systems.
- Regulatory frameworks for microbial products differ across countries.

Moreover, introducing microbes into aquaculture systems requires careful safety evaluation to avoid unintended ecological consequences. Research is ongoing to standardize formulations and validate long-term benefits.

Conclusion

Aquaculture has entered a new era. Beyond genetics, beyond feeds, beyond infrastructure, the future may lie within the microscopic ecosystems living inside every fish. Fish gut microbiome engineering represents a shift in perspective. It reminds us that health and productivity are not determined by the host alone, but by a partnership between the fish



and its microbial allies. In the coming years, fish farms may not just manage water quality and feeding schedules. They may manage microbial communities with the same precision.

References

- Singh, B.K., Thakur, K., Kumari, H., Mahajan, D., Sharma, D., Sharma, A.K., Kumar, S., Singh, B., Pankaj, P.P. and Kumar, R., 2025. A review on comparative analysis of marine and freshwater fish gut microbiomes: insights into environmental impact on gut microbiota. *FEMS Microbiology Ecology*, 101(1), p. fiae169.
- Yang, J.H., Park, J.W., Kim, H.S., Lee, S., Yerke, A.M., Jaiswal, Y.S., Williams, L.L., Hwang, S. and Moon, K.H., 2024. Effects of antibiotic residues on fish gut microbiome dysbiosis and mucosal barrier-related pathogen susceptibility in zebrafish experimental model. *Antibiotics*, 13(1), p.82.
- Rai, N., Kachore, A., Julka, J.M., Panigrahi, A., Das, S.P. and Nan, F.H., 2025. Symbiotic strategies: deciphering the role of gut microbiota in the nutrition and metabolism of fish and shellfish. *Frontiers in Cellular and Infection Microbiology*, 15, p.1639426

