Popular article ISSN:2583-4150

VACCINATING THE UNDERWATER WORLD: FISH VACCINES EXPLAINED

Kukkadhuvu Sindhuvasuki[1], Mavurapu Anusha[2], Manupati Sneha[3], Voraganti Divija[4]

[1]Kerala University of Fisheries and Ocean Studies, Panangad, Kochi 682506, Kerala, India

[2] College of Fishery Science, PV Narsimha Rao Veterinary University, Telangana - 509104, India.

[3]ICAR - Central Institute of Fisheries Education, Versova, Mumbai, Maharashtra, 400061, India

[4]TamilNadu Dr. Jayalaitha Fisheries University, Thoothukudi, TN-628008, India.

*Corresponding author: vasuk5898@gmail.com
Accepted on Aug 18, 2026

Introduction

Fish live in complex aquatic environments, in contrast to land animals. Every pathogen in pond or cage water is in constant, direct contact with the fish's gills, skin, and gut, which makes infectious disease one of the most persistent threats to aquaculture worldwide. For decades, antibiotics were the farmer's default answer, but rising antimicrobial resistance and stricter export regulations have pushed the industry to look for prevention rather than cure. Vaccination has emerged as one of the most effective tools for this shift. In human childhood, vaccines train the immune system to recognise a threat before it strikes; similarly, fish vaccines prepare the immune system of farmed fish to fight off infection before it takes hold, often dramatically reducing mortality and antibiotic use on well-managed farms (Mondal & Thomas, 2022).

Why Vaccination Matters More in Water-Based Farming

Unlike livestock reared on land, fish are permanently immersed in the very medium that carries most of their pathogens. A single contaminated pond can expose an entire stock simultaneously, and disease can spread from one cage to another through shared water in a matter of hours. This makes prevention far more valuable than treatment in aquaculture. Vaccination not only reduces mortality but also lowers reliance on antibiotics, supporting both farm profitability and the broader push toward antimicrobial stewardship in aquatic food production (Mondal & Thomas, 2022).

Types of Fish Vaccines

Fish vaccines have evolved considerably since the first commercial products appeared in the 1970s. Whole-cell inactivated vaccines, made by killing a cultured pathogen while preserving its antigens, remain the most widely used type in global aquaculture because they are relatively simple and inexpensive to produce (Adams, 2019). Live-attenuated vaccines use a weakened form of the pathogen, closely mimicking natural infection and often producing a stronger, longer-lasting immune response. More recently, subunit and recombinant vaccines have been developed using genetic engineering to isolate just the protein fragment of a pathogen needed to trigger immunity. One well-known example is the VP2 subunit vaccine used against infectious pancreatic necrosis virus in Norwegian salmon farming (Adams, 2019; Van Muiswinkel & Nakao, 2014). The information on major categories of fish vaccines and their mode of action is provided in Table 1.

Delivery Methods: Injection, Immersion, and Oral

How a vaccine is delivered matters almost as much as what it contains. Injection remains the gold standard for strong, long-lasting immunity, but it requires handling each fish individually, which is labour-intensive and stressful for the animals. Immersion vaccination, where fish are briefly bathed in a vaccine solution, is far less stressful and suitable for mass application at the hatchery stage, though it generally offers a shorter duration of protection. Oral vaccination, delivered through medicated feed, is the least stressful and most scalable method, but protecting the vaccine antigen from degradation in the fish's digestive tract remains a technical challenge. Encapsulation technologies, including chitosan and alginate nanoparticles, and even engineered microalgae as oral antigen carriers, are being developed to solve this problem (Adams, 2019; Nature Index, 2024).

Mechanism of action of vaccine in fish

To understand how vaccination works inside the fish, the process after a vaccine is administered is depicted in Figure 1. The process begins when the vaccine, delivered by injection or immersion, is taken up by immune cells called antigen-presenting cells, which break down the pathogen and display its fragments to the fish's T and B cells. This activation triggers B cells to produce protective antibodies, while a portion of these cells become long-lived memory cells. The next time the fish encounters the same pathogen, these memory cells allow a much faster, stronger response; this is the basic principle behind why vaccinated fish survive infections that would otherwise cause serious disease or death.

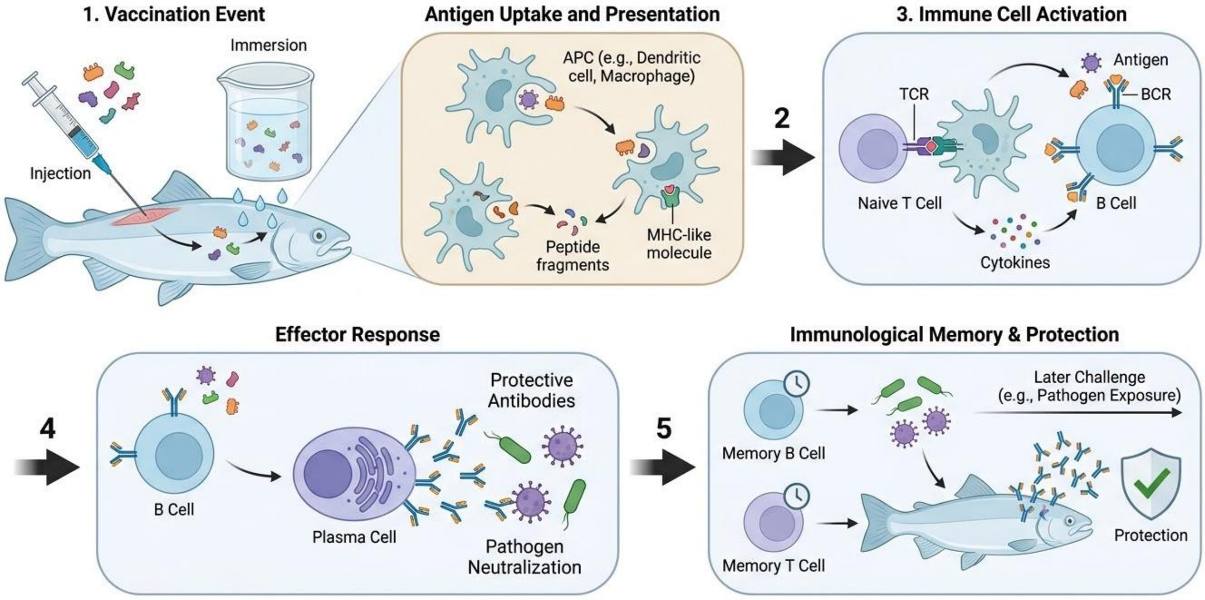

Figure 1. Mechanism of action of fish vaccines, showing antigen uptake and presentation, immune cell activation, antibody production, and the formation of immunological memory that protects against future pathogen exposure.

Recent Advances: DNA, RNA, and Recombinant Vaccines

The most significant recent shift in fish vaccinology has been the move toward nucleic-acid-based vaccines. DNA vaccines work by introducing a plasmid carrying a pathogen gene into fish cells, which then produce the antigen themselves to trigger immunity; one recent study showed that grass carp given an oral DNA vaccine encapsulated in chitosan or alginate nanoparticles were well protected against grass carp reovirus infection (Huo et al., 2023). RNA and self-amplifying RNA vaccines are an even newer platform, offering a faster immune response and avoiding any risk of the vaccine material integrating into the fish's own genome, unlike DNA vaccines, which require nuclear uptake of the plasmid (Miyazato et al., 2024). These nucleic-acid platforms also tend to have simpler manufacturing pathways, which could reduce dependence on the cold-chain logistics that make traditional vaccines difficult to distribute to remote fish farms.

Challenges in Adoption

Despite the scientific progress, several practical barriers slow the adoption of advanced fish vaccines. Cost remains a major constraint, particularly for small-scale farmers in developing regions who make up most of the world's aquaculture producers. Achieving strong immunity through oral vaccines is still difficult because antigens can be broken down before they reach the fish's immune system. Environmental stress, water temperature fluctuations, and the sheer diversity of pathogens across regions and species also complicate the design of a single, broadly effective vaccine (Chaves-Pozo et al., 2022; Mondal & Thomas, 2022). Bridging the gap between laboratory-stage nucleic acid vaccines and affordable, farm-ready products will likely define the next decade of aquaculture vaccinology.

Overview of Fish Vaccine Types

Vaccine Type	How It Works	Example Use
Whole-cell inactivated	Killed pathogen retains antigens to trigger immunity	Most common commercial fish vaccines worldwide
Live-attenuated	Weakened pathogen mimics natural infection for stronger response	Oral/immersion vaccines against bacterial disease
Subunit / recombinant	Uses only a specific pathogen protein, produced via genetic engineering	IPNV VP2 subunit vaccine (salmon, Norway)
DNA vaccine	Plasmid carrying pathogen gene is taken up by fish cells to produce antigen	Oral chitosan/alginate-encapsulated DNA vaccine against grass carp reovirus
RNA / mRNA vaccine	mRNA instructs cells to produce antigen directly in the cytoplasm	Emerging platform, faster response, no cold-chain dependence
Peptide vaccine	Synthetic antigenic peptide fragments stimulate antibody response	Tested against IPNV and ISAV in Atlantic salmon

Table 1. Major categories of fish vaccines used or under development in aquaculture

Conclusion

From the earliest inactivated whole-cell vaccines to today's experimental RNA platforms, fish vaccination has come a long way in giving farmers a preventive alternative to antibiotics. As nucleic-acid vaccines, nanoparticle delivery, and oral carriers like engineered microalgae continue to mature, the vision of low-stress, mass-scale vaccination for even small farms is becoming more realistic. For an industry under growing pressure to reduce antibiotic use while feeding a growing global population, vaccines are no longer a luxury; they are becoming a necessity.

References

Adams, A. (2019). Progress, challenges and opportunities in fish vaccine development. Fish & Shellfish Immunology, 90, 210–214.

Chaves-Pozo, E., Valero, Y., & Lozano-Aguilar, S. (2022). Advancements in Fish Vaccination: Current Innovations and Future Horizons in Aquaculture Health Management. Applied Sciences, 14(13), 5672.

Mondal, H., & Thomas, J. (2022). A review on the recent advances and application of vaccines against fish pathogens in aquaculture. Aquaculture International, 30, 1971–2000.

Nature Index (2024). Vaccine Development Strategies in Aquaculture Fish. Nature Research Intelligence Topic Summary.

Van Muiswinkel, W. B., & Nakao, M. (2014). A short history of research on immunity to infectious diseases in fish, in the context of vaccine development. In Fish Vaccination (pp. 1–11). Wiley.

ScienceDirect (2025). The present landscape of both traditional and innovative biotechnology-driven vaccines for fish diseases in global aquaculture. Aquaculture and Fisheries.