International Journal of Biotechnology and Microbiology
www.biotechnologyjournals.com
Online ISSN: 2664-7680
Received: 05-04-2026, Accepted: 06-05-2026, Published: 21-05-2026
Volume 8, Issue 2, 2026, Page No. 100-103

The role of Biotech in advancing sustainable fish farming

V Mohan Raj
Department of Zoology, Sir Theagaraya College, Chennai, Tamil Nadu, India

Abstract
Biotechnology has emerged as a cornerstone of modern aquaculture, utilizing advanced methods like genetic engineering and selective breeding to improve disease resistance and accelerate growth rates in aquatic species. As the fastest-expanding segment of the agricultural industry, fish farming is currently vital in meeting the world's surging appetite for seafood. This rising consumer demand is colliding with a critical environmental crisis: the rapid depletion of wild fish populations caused by unsustainable over-fishing. With aquaculture already supplying more than 18 million tons of seafood to the global food chain annually, researchers are increasingly turning to biotechnological innovation to bridge the gap between supply and demand. By leveraging these technologies, scientists can isolate and merge desirable genetic traits to ensure both superior quality and higher yield.

Keywords: Aquaculture, technology, hybrid, vaccines, transgenesis, seafood

Introduction

Throughout history, humanity has consistently harnessed technology to simplify existence. Today, as global appetite for seafood continues to climb, traditional wild-capture fishing has reached a critical threshold, with many marine and freshwater stocks approaching their ecological breaking points. As noted by Rehman *et al*., (2022) [16], the expansion of aquaculture, bolstered by biotechnological innovation, serves as a vital solution to bridge the gap between supply and demand. The integration of modern biotechnology into fish farming holds transformative potential. Over the past few decades, scientific breakthroughs have provided researchers with sophisticated tools to intervene at the genetic and chromosomal levels. The development of transgenic aquatic species remains a focal point of marine science, specifically for its capacity to significantly elevate production yields (Zbikowska, 2003; Dunham, 2004) [22,7].

Beyond mere volume, biotechnology provides an environmentally sustainable pathway to support the needs of a modern, industrialized global population. However, the successful implementation of these techniques requires a deep, interdisciplinary understanding of the physiology, genetics, biochemistry, and pathology of the organisms being modified. Genetic engineering a core pillar of contemporary biotechnology is the culmination of decades of progress in molecular and cellular biology (Rehman *et al*., 2022) [14]. By allowing scientists to isolate, extract, and reconfigure specific genes, this technology has revolutionized fields ranging from forestry and livestock management to horticulture and food production (Opabode and Adebooye, 2005; Ezeonu *et al*., 2012) [13,8].

In the context of fisheries, the depletion of natural resources has turned research toward aquaculture as an essential field of study (Billington and Hebert, 1991) [4]. Scientists are now utilizing biotechnological tools to identify and integrate traits that optimize both profitability and yield. Current efforts are particularly focused on pinpointing genomes that accelerate growth rates and enhance the natural immune responses that protect aquatic animals from microbial infections.

The aquaculture industry currently stands as one of the world's most rapidly expanding sectors. To meet the escalating global demand for seafood compounded by the degradation of natural marine habitats biotechnology has become an essential instrument for modernizing fisheries and food production. By leveraging genetic advancements, scientists can now refine the traits of fish and shellfish to enhance growth rates, bolster productivity, and improve overall quality. Current research focuses on identifying genes that stimulate natural growth parameters and bolster the innate immune systems of aquatic organisms against pathogens. As noted by Vishwanatham *et al*., (2024) [21], while contemporary biotechnology presents certain technical hurdles, its potential to revolutionize aqua-farming and ensure future food security is immense. This paper evaluates the diverse applications of these biotechnological interventions and their capacity to reshape the future of the aquaculture industry.

Provide an alternative protein source for fish

Fish meal remains the primary protein source in aquaculture, valued for its high nutritional profile and role as a byproduct of fish processing. However, its continued reliance faces significant hurdles. Economically, its high cost necessitates the search for more affordable substitutes. Supply chains are also increasingly unstable due to the depletion of wild fish stocks. Furthermore, fish meal poses environmental risks; its significant phosphorus content promotes eutrophication, leading to harmful algal blooms in aquatic ecosystems. While plant-based proteins offer a sustainable, low-phosphorus alternative, they often contain anti-nutritional factors that can impede fish growth. Consequently, modern biotechnological methods are now being employed to eliminate these inhibitors and enhance the digestibility of plant-derived feed.

Genetic Hybrids

The foundation of premium aquatic produce lies primarily in the caliber of the parent stock. Utilizing robust, healthy specimens minimizes the risks of congenital defects or inherited illnesses, which ultimately safeguards the final market value of the harvest. Historically, prior to the modernization of aquaculture, producers relied heavily on phenotypic observation and pedigree analysis to select the best breeding candidates (Abdelrahman *et al*., 2017) [1]. The primary goal of these selective breeding and hybridization efforts is to enhance economically significant traits, including superior growth rates, efficient nutrient conversion, increased flesh yield, and heightened resilience against disease and environmental stressors (Bakos and Gorda, 1995; Senanan *et al*., 2004) [2,16]. Livestock exhibiting these optimized characteristics generally thrive in commercial settings and command a premium price.

Modern advancements in genetic improvement have expanded the toolkit to include sophisticated techniques such as polyploidy, sex control, xenogenesis, gene editing, and genome-enabled selection (Abdelrahman *et al*., 2017) [1]. These breakthroughs have led to vast improvements in stock quality, allowing for the tailoring of aquatic animals to specific environmental constraints or evolving consumer preferences. Undeniably, genetic modification has proved instrumental in boosting survival rates across farming operations. However, because these interventions carry the potential for permanent ecological consequences, many nations now enforce rigorous legislative frameworks to regulate genetic research and ensure the responsible application of these technologies.

Biotechnology in fish breeding

Gonadotropin-releasing hormone (GnRH) currently stands as the premier biotechnological instrument for facilitating the induced spawning of fish. As the primary initiator of the reproductive process across all vertebrates (Bhattacharya *et al*., 2002) [3], this decapeptide was initially identified within porcine and ovine hypothalami, where it was found to trigger the pituitary secretion of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) (Schally *et al*., 1971) [15]. While placental mammals generally possess a single variant of this neuropeptide, non-mammalian species exhibit greater diversity. Research has identified twelve distinct GnRH structural variants in non-mammals, with seven or eight of these forms discovered specifically in fish (Halder *et al*., 1991) [10]. Following the ongoing characterization of these variants most recently by Carolsfeld *et al*., (2000) [5] scientists have developed various synthetic analogues. The most prominent of these is a salmon GnRH analogue, widely distributed in the aquaculture industry under trade names like Ovaprim, which has revolutionized the success of artificial fish breeding.

Vaccines

Contemporary advancements in technology have proven highly beneficial for the aquaculture industry, specifically regarding the use of vaccines and immunostimulants to safeguard fish health. By bolstering immunity or providing proactive protection, these tools have become a vital part of disease management. As noted by Subasinghe (2009) [17], fish immunization has evolved over the past thirty years into a reliable, economically viable strategy for mitigating infectious outbreaks in global fish farming operations.

Currently, various commercial vaccines are available to combat conditions like furunculosis (*Aeromonas salmonicida*), with others such as those targeting viral hemorrhagic septicemia (VHS) currently in the research pipeline. Beyond minimizing animal mortality, immunization offers significant environmental and safety advantages; it decreases reliance on antibiotic treatments, eliminates chemical residues in both the ecosystem and the final food product, and prevents the development of drug-resistant pathogens (Subasinghe, 2009) [17].

Application methods vary depending on the target species, ranging from feed additives and immersion baths to direct injections for larger fish. Furthermore, the field is expanding into genetic engineering to enhance efficacy. A notable breakthrough includes the use of DNA-based vaccines, such as the successful administration of a glycoprotein gene to rainbow trout, which has demonstrated strong protective immunity against the VHS virus.

Transgenesis

Transgenic technology represents a revolutionary approach to aquaculture, providing a sophisticated method for enhancing the genetic characteristics of high-value aquatic species, including crustaceans, mollusks, and fish. By integrating foreign DNA into an organism's genome, scientists can ensure that these new traits are consistently expressed and passed down to future generations. Significant progress has been realized in various fish species, most notably in Salmonids, where growth rates have been vastly accelerated. Research by Diwan and Kandasami (1997) [6] highlighted that some transgenic salmon reached sizes three to five times larger than their conventional counterparts, with select specimens growing up to 30 times faster during their initial development.

Beyond growth, researchers have focused on increasing the thermal tolerance of aquatic species, particularly regarding cold-water survival (Hew *et al*., 1995) [11]. Since extreme cold is a significant obstacle for aquaculture in frigid regions, the study of antifreeze proteins (AFP) and glycoproteins (AFGP) found in specific marine teleosts offers a potential solution. These proteins hinder ice-crystal formation, allowing fish to thrive in near-freezing conditions. Experiments have shown that administering these proteins to species like tilapia or milkfish can significantly boost their ability to withstand drastic drops in water temperature (Ezeonu *et al*., 2012) [8].

Looking ahead, embryonic stem cell (ESC) technology stands out as the most viable path for the future of transgenic fish farming. Because these cells are totipotent and undifferentiated, they can be laboratory-modified and integrated into early embryos to influence the host's germ line, allowing for precise gene insertion or deletion. According to Tanekhy (2020) [19], the full potential of this field depends on several key advancements: improving mass gene transfer efficiency, perfecting targeted gene editing, utilizing precise promoters to control gene expression, identifying beneficial genes, optimizing environmental and nutritional conditions for transgenic organisms, and performing rigorous assessments of environmental safety and ecological impact.

Fish Health Management

The aquaculture industry faces significant hurdles due to recurring disease outbreaks, which remain a primary obstacle to sustainable growth. To address these challenges, the global aquaculture sector is increasingly adopting biotechnological solutions including advanced diagnostics, immunostimulants, and vaccines to bolster the health and resilience of both finfish and shellfish. While traditional vaccines, which utilize inactivated microorganisms, have long been the standard for protecting fish against bacterial and viral infections, the field is evolving. Researchers are now actively developing next-generation immunization strategies, such as DNA vaccines, genetically engineered organisms, and protein subunit vaccines.

When dealing with viral pathogens, prevention through the total avoidance of infection is critical. Consequently, there is an urgent demand for rapid, highly sensitive diagnostic techniques. Modern molecular tools, particularly gene probes and polymerase chain reaction (PCR) technology, have emerged as highly effective solutions for this purpose. These PCR-based methods have already been successfully pioneered for the detection of various pathogens in shrimp and finfish populations (Karunasagar, 1999) [12].

Vaccines

Vaccines consist of specific antigen preparations derived from pathogenic organisms that have been neutralized to eliminate their virulence. As noted by Ha *et al*., (2008) [9], these formulations trigger an immune response, thereby enhancing the host's ability to resist subsequent infections. In aquaculture, vaccination functions as a proactive strategy to minimize financial losses associated with fish mortality, disease outbreaks, and the costs of medical treatment. Although the concept of fish immunization dates back to the 1940s, it was David CB. Duff's foundational research that earned him the title of the "Father of fish vaccination" (Vaseeharan and Jesudhasan, 2024) [20]. It is important to note that vaccines offer pathogen-specific immunity; for example, protection against *Streptococcus iniae* does not extend to *Vibrio anguillarum*. Furthermore, vaccine delivery systems vary, with injectable versions typically utilizing oil-based adjuvants to boost immunological efficacy.

Conclusion

The field of biotechnology is currently undergoing rapid expansion, emerging as a pivotal force in driving advancements within human health, agriculture, and fisheries. By providing sophisticated methodologies for the manipulation of genes and the development of innovative genotypes across various species, this science has unlocked unprecedented potential. Although the integration of biotechnological practices into aquaculture is a nascent development, it holds significant promise for boosting productivity. Furthermore, the strategic implementation of these technologies is poised to transform the aquaculture industry while simultaneously contributing to the preservation of aquatic biodiversity."

References

1. Abdelrahman H, ElHady M, Alcivar-Warren A, Allen S, Al-Tobasei R, Bao L, *et al*. Aquaculture genomics, genetics and breeding in the United States: current status, challenges, and priorities for future genomics,2017:18(1):191.
2. Bakos J, Gorda S. Genetic improvement of common carp strains using intraspecific hybridization. Aquaculture,1995:129(1-4):183-186.
3. Battacharya S, Dasgupta S, Datta M, Basu D. Biotechnology input in fish breeding. Indian journal of biotechnology,2002:1:29-38.
4. Billington N, Hebert P. Mitochondrial DNA diversity in fishes and its implications for introductions. Canadian Journal of Fisheries and Aquatic Sciences,1991:48:80-94.
5. Carolsfeld J, Powell Jk, Park M, Fisher WH, Craig AG, Chang JP, *et al*. Primary structure and function of three gonadotropin releasing hormone. Endocrinology,2000:141:505-512.
6. Diwan AD, Kandasami D. Freezing of viable embryo and larvae of marine shrimp *P. semisulcatus* de haan. Aquaculture research,1997:28:947-950.
7. Dunham RA. Aquaculture and fisheries biotechnology: Genetic approaches, 2nd ed., CABI, Preston, UK, 2004.
8. Ezeonu CS, Richard Tagbo R, Anike EN, Obinna A, Oje A, Ikechukwu NEO.. Biotechnological Tools for Environmental Sustainability: Prospects and Challenges for Environments in Nigeria. A Standard Review Biotechnology Research International, 2012, 10-26.
9. Ha SJ, West EE, Araki, Smith KA, Ahmed R. Manipulating both the inhibitory and stimulatory immune system towards the success of therapeutic vaccination against chronic viral infections. Immunological reviews,2008:223(1):317-333.
10. Halder S Sen, Bhattachery S, Ray AK, Ghosh A, Jhingran AG. Induced spawning of IMC and maturation of a perch and a catfish by murrel gonadotropin releasing hormone, pimozide and calcium aquaculture,1991:97:373-382.
11. Hew CL, Fletcher G, Davies PL. Transgenic salmon:tailoring the genome for food production. J. Fish Biol,1995:47:1-9.
12. Karunasagar I, Karunasagar I. Diagnosis treatment and prevention of microbial diseases of fish and shellfish. Curr. Sci,1999:76:387-399.
13. Opabode JT, Adebooye OC. Application of biotechnology for the improvement of Nigerian indigenous leaf vegetables. African Journal of Biotechnology,2005:4:138-142.
14. Rehman SMU, Aleem MT, Umar M, Khan A, Jamil M, Rehman TU, Ijaz A, Hussain J, Abbas RZ. Advancement in aquaculture system by applying biotechnological tools. In: Abbas RZ, Khan A, Liu P, Saleemi MK (eds), Animal Health Perspectives, Unique Scientific Publishers, Faisalabad, Pakistan,2022:1:259-265.
15. Schally AV, Arimura A, Baba Y, Nair RM, Matsuo H, Redding TW, Debeljuk L. Isolation and properties of the FSH and LH-releasing hormone. Biochem Biophys Res Commun,1971:43(2):393-9.
16. Senanan W, Kapuscinski AR, Na-Nakorn U, Miller LM. Genetic impacts of hybrid catfish farming (*Clarias macrocephalus* × *C. gariepinus*) on native catfish populations in central Thailand. Aquaculture,2004:235(1-4):167-184.
17. Subasinghe R. Disease control in aquaculture and the responsible use of veterinary drugs and vaccines: The issues, prospects and challenges. Options Mediterraneennes, 2009, 86.
18. Subasinghe RP, Bonad-Reamtaso MG. Biosecurity in Aquaculture: International Agreements and instruments, their compliance, prospects and challenges for Developing countries, pp.9-16. In: Scarfe AD, Lee CS, Bryen PO. (eds). Aquaculture Biosecurity: Prevention, Control and Eradication of Aquatic Animal disease: Blackwell publishing, 2006, 182.
19. Tanekhy M. Applications of biotechnology in fish. Egyptian J. Anim. Prod. 57 Suppl. Issue, January, 2020, 157-161.

20. Vaseeharan B, Jesudhasan P. Vaccines in Aquaculture: Development, Production, and Applications. Elsevier, 2024.
21. Vishwanatham K, Bhukya Sai Kumar, Dharavath Ram Kumar. Application Of Biotechnology In Aquaculture. Journal of Advanced Zoology,2024:45(03):797-800.
22. Zbikowska H. Fish can be First – Advances in Fish Transgenesis for Commercial Applications. Transgenic Research,2003:12:379–389.