DOI: https://doi.org/10.54083/978-81-980121-3-5_04

Biotechnology in Aquaculture: Unlocking Potential

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Abstract

Applications of genetics and biotechnology to improve aquaculture have increased dramatically in recent years. Research in fisheries encompasses study of evolution, biology, metabolic processes, population structure, aquatic ecology, disease management, bringing out desirable qualities in fish that benefit people, conservation biology, among other topics. Much advancement in biotechnological applications, including molecular markers, disease diagnostic kits, fish vaccines, biomarkers and stem cell procedures, have been made in recent decades. In the fields of biological, agricultural and industrial sciences, biotechnology has long been a patronage. Biotechnological applications are used in many different domains, such as waste management, energy production, bioremediation, diagnostics and medicines. It has been successful in changing the landscape of fisheries with the introduction of cutting-edge cellular, molecular and genetic technologies. The industry is expanding more quickly than it has ever done, eschewing the slower and more economically draining traditional methods in favour of biotechnology. In addition to creating jobs for the nation's constantly expanding workforce, the fishing industry has enormous potential to propel the economy into new heights. The use of biotechnology to improve aquaculture productivity through genetic engineering, selective breeding, disease control and the creation of bio-based diets has been a prominent view in recent years. It talks about how molecular methods like CRISPR are being applied to enhance disease resistance, boost growth rates and improve fish genetics. It also looks into how immune-stimulants, probiotics and vaccinations can improve health in farmed animals and lessen the need for antibiotics.

Keywords Applications, Aquaculture, Biotechnology, Production

1. Introduction

The development of rural areas is strongly influenced by fisheries and aquaculture by providing food and nutritional security, alleviating poverty, driving economic growth and supporting employment and livelihoods in rural communities. Aquaculture, which now accounts for over 45% of global

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How to cite:

Malla, S., Kumar, S., 2025. Biotechnology in aquaculture: Unlocking potential. In: *Aquaculture Reimagined: Modern Approaches to Sustainable Fish Farming*. (Eds.) Saini, V.P., Paul, T., Singh, A.K., Biswal, A. and Samanta, R. Biotica Publications, India. pp. 41-49. DOI: https://doi.org/10.54083/978-81-980121-3-5_04.

fish consumption, is the fastest-growing food production sector, with an annual growth rate of 8-10%, far surpassing livestock at 3% and capture fisheries at 1.6% (FAO, 2022). The global trade in fish and fishery products continues to expand rapidly. Additionally, aquaculture is a highly diverse sector, varying widely in species, systems, environments, operations, scale, intensity and management practices. Every year, thousands of fish farmers face innumerable losses, related to unforeseen factors, management and operational errors or technical failures (Pontecorvo and Schrank, 2009). Every year, thousands of fish farmers experience significant losses due to unforeseen factors, management errors and technical failures. It is necessary to integrate technology across numerous fields in order to develop effective fish farming projects in order to combat these challenges (Charles, 2023). Fish farming technology more than just knows how to raise fish; it's about building a business that can last and make a profit for many years, staying strong even when challenges arise.

The adoption of technological innovations is showing positive results globally in terms of aquaculture diversification, investment potential and the exchange of international technology. Biotechnology are becoming increasingly important in aquaculture, helping in greater productivity, sustainability and disease management. They help to improve the fish breeding by creating fish that grow faster, diseases resistant variety and use food more efficiently (high FCR valued fish). Early diagnosis of disease and by developing vaccines can protect fish from infections. Cryopreservation techniques allow the long-term storage of fish eggs and sperm, preserving valuable breeds. Lastly, tools for monitoring water quality ensure that fish farming environments remain healthy. These advancements are making aquaculture more efficient and eco-friendly. In the future, new innovations in culture system designs will contribute to exponential growth in production (Behera *et al.*, 2003).

2. Biotechnology

Biotechnology focuses on developing products, methods and organisms to improve human health and society. Biotechnology, often referred to as biotech, has existed since the beginning of civilization with the domestication of plants and animals and the discovery of fermentation. Following are the six (6) areas, applications and scopes of biotechnology:

a) Red biotechnology (Red Biotech): Medical biotechnology/ Bio-pharmaceutical

b) Yellow biotechnology (Yellow Biotech): Nutrition and Food biotechnology

c) Green biotechnology (Green Biotech): Agricultural production and Environmental biotechnology

d) Blue biotechnology (Blue Biotech): Freshwater and coastal/ marine life biotechnology

e) White biotechnology (White Biotech): Industrial biotechnology

f) Purple biotechnology (Purple Biotech): Patents and Intellectual Property (IP) biotechnology

Further, the application of biotechnology includes- therapeutics, diagnostics, genetically modified crops for agriculture, processed food, bioremediation, waste treatment, energy production and the steps of the biotechnology process:

a) Locating an organism with a specific trait and extracting its DNA.

b) Cloning a gene that controls the trait.

c) Constructing a gene to express in a specific way.

d) Transformation, inserting the gene into the cells of a crop plant.

e) Cross the transgene into an elite background.

2.1. Aquaculture Productivity Enhancement through Advanced Technologies

The aquaculture industry has changed a lot due to modern technologies. "Smart aquaculture," also called the "third green revolution," uses advanced technology to make production and decision-making smarter, improving the quality and output of aquaculture (Zhang *et al.*, 2022). With the growing global demand for fish and seafood, sustainable development in aquaculture is becoming more urgent. Modern molecular methods like transgenesis, gene targeting and microRNA can greatly boost productivity in intensive aquaculture by speeding up growth, improving feed efficiency, reducing feed costs and enhancing stock by directly modifying genes linked to growth, disease resistance, or reproduction control (Lu *et al.*, 2019). These innovations significantly cut production costs, making protein more affordable, especially for economically weaker groups. Additionally, aquatic organisms can be used to produce important medicines. Given these benefits, aquaculturists are encouraged to adopt the latest technologies developed by scientists to improve aquaculture production and efficiency (Danish *et al.*, 2017).

2.2. Genetic Engineering Tool and Technique

Genetic engineering tools are making significant strides in aquaculture, offering innovative solutions to enhance fish growth, disease resistance and overall productivity. Here are some of the tools and techniques that have been widely adopted by the aquaculturist (Figure 1).

2.2.1. CRISPR-Cas9

The clustered regularly interspaced short palindromic repeats (CRISPR)-CRISPR-associated protein 9 (Cas9) systems is the revolutionary gene-editing technology allows scientists to make precise modifications to the DNA of fish. This technology allows one to precisely manipulate virtually any genomic sequence specified by a short stretch of guide RNA/DNA, allowing elucidation of gene function involved in disease development and progressions, correction of disease-causing mutations and inactivation of activated oncogenes (Charpentier, 2013). This tool is favored for its accuracy, cost-effectiveness and ability to edit multiple genes simultaneously, opening new avenues for improving aquaculture species.

2.2.2. RNA Interference (RNAi)

RNAi is a powerful technique that silences specific genes to prevent the expression of unwanted traits. This method is particularly useful in enhancing disease resistance by targeting genes that make fish susceptible to infections and by manipulating gene expression, RNAi can improve the immune response of fish, making them more resilient to diseases such as viral infections and parasites (Abo-Al-Ela, 2021) . This technique allows for more targeted interventions, reducing the need for antibiotics and promoting healthier aquaculture practices.

2.2.3. Transgenesis

A transgene is a gene that is introduced into the genome of a different organism to give it enhanced traits. This results in genetically modified organisms (GMOs). Aquaculture has benefited from transgenic fish with improved growth rates and feed conversion efficiencies. In AquaBounty salmon, for instance, growth hormone genes from other fish species have been used to make the fish grow faster. In addition to boosting productivity, transgenesis also helps meet the global demand for fish.

2.2.4. Next-Generation Sequencing in Aquaculture and Fisheries

The aquaculture industry faces several challenges that lower fish production, resulting in significant economic losses. Using NGS technologies has helped identify SNPs, microRNAs and genes linked to faster growth, sex determination, disease response, reactions to pollutants and the effects of human activities on fish migration and genetic diversity. Although genomics and transcriptomics have advanced, more in-depth research is crucial due to the high diversity of economically and ecologically important fish species (Khan *et al.*, 2021). Progress in genomics and big data analysis is expected to uncover the complex genetic networks and pathways for selecting desirable traits.

2.2.5. Genome Sequencing in Fishes

Many fish genome projects have produced a large amount of data on genome structure and function, which serves as a foundation for further research. Decoding the nucleotide sequences, genes, markers and their links to different genome regions can help improve traits using whole-genome selection. Specific traits have been linked to SNPs (single nucleotide polymorphisms) on a genomic scale and used to select individuals or strains with better qualities. However, in India, fish genome sequencing is still in its early stages. The Indian fisheries sector needs to expand its potential by generating more genomic data from Indian fish species. Fully sequenced and annotated genomes would provide insights into the genetic organization of Indian fish and generate species-specific information (Eid *et al.*, 2009). This sequencing can help identify and modify genes for beneficial traits like faster growth, better coloration, disease resistance and tolerance to cold or salty environments. The genomic data collected will also be used to create SNP chips and expression arrays to detect economically important traits (Chen *et al.*, 2013).

2.2.6. Genome Editing

Reverse genetics methods are essential for understanding how genes work and for editing or engineering genomes. Traditionally, creating gene-editing models relied heavily on embryonic stem cells (ESCs), which were available in only a few species like mice and rats. In mice, homologous recombination (HR)-based editing introduced the possibility of precise genome modifications. However, because HR methods and ESCs were not available for many species, including fish that can be cultured, gene editing in these organisms was not feasible. This has changed with the advent of engineered nucleases,

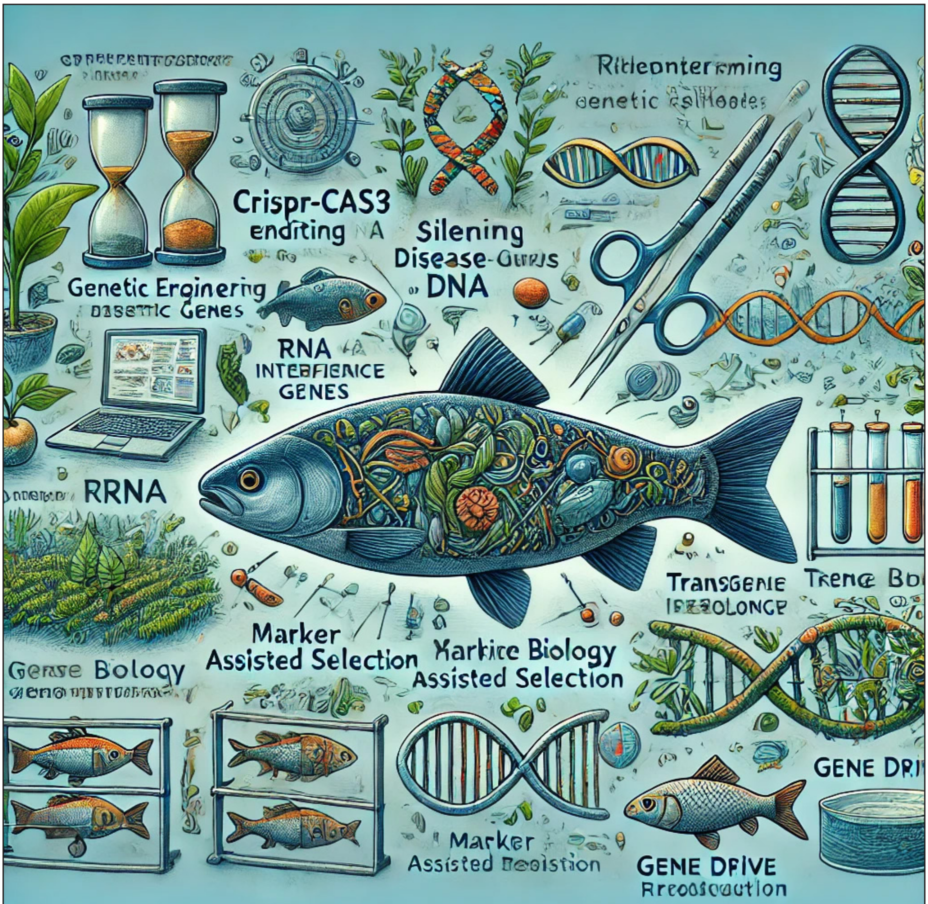

Figure 1: Different genetic engineering tools and techniques used in aquaculture

which now enable precise genome editing in a wide range of species, from invertebrates to vertebrates (Mishra *et al.*, 2023). Unlike transgenesis, where a gene is transferred between species, genome editing makes specific, minor changes to the genome without adding foreign DNA, making it a viable option for producing food-grade "gene-modified organisms."

3. Omics Tools: A New Era in Aquaculture Development

The rapid growth of aquaculture is mainly driven by the use of advanced technology and the recent progress in the omics era, which began with genomics. Genomics focuses on studying an organism's complete set of genes (genome) (Hasin *et al.*, 2017). It offers detailed insights into individual genes, chromosomes, their arrangement, genetic variations and evolutionary links with other groups. However, genomics cannot provide information about gene expression, functions, regulation, or the structure and features of the proteins encoded by these genes (Kavallaris *et al.*, 2005). These gaps led to the emergence of the post-genomic era, dominated by transcriptomics and proteomics. Transcriptomics studies the complete set of RNA molecules (transcriptome) produced by a genome under specific environmental conditions (Hegde *et al.*, 2003). It reveals details about various RNA types, gene structures and gene expression. Still, it doesn't show the actual protein content due to processes like post-transcriptional modifications and alternative splicing. Proteomics, which came after transcriptomics, examines proteomes - the complete set of proteins, which play a central role in biological processes (Hegde *et al.*, 2003).

4. Next-Generation Sequencing (NGS) Dominance

The present era is characterized by the dominance of Next-Generation Sequencing (NGS) technologies, which have overcome many of the drawbacks of Sanger sequencing. NGS platforms, including Illumina, Ion Torrent and Pacific Biosciences, enable high-throughput sequencing of DNA and RNA, making it feasible to analyze entire genomes and transcriptomes rapidly and cost-effectively. NGS has revolutionized genomics research, contributing to the understanding of genetic variations, gene expression patterns and the role of non-coding RNA. It has become an essential tool in fields such as personalized medicine, cancer genomics and evolutionary biology. The Human Genome Project, completed in 2003, was a landmark achievement that utilized NGS to decode the entire human genome. NGS can also be performed at transcriptome level which includes entire assembly of RNA transcripts in a given cell type including mRNA, rRNA, tRNA, micro-RNA and non-coding RNA. Unlike DNA sequencing, this is called RNA sequencing. Specially designed mRNA sequencing is also often used to detect fusion genes. The most commonly used NGS assay for cancer patients is targeted panel sequencing which usually interrogates dozens or hundreds of targeted genes. Compared to whole genome sequencing, such targeted panel has only limited targets. Therefore, it allows a lot more depth in sequencing, which is necessary to cover different mutations with different allelic mutation frequencies. The high demand for low-cost sequencing has driven the development of high throughput sequencing, which produces thousands or millions of sequences at once (Shendure *et al.,* 2008). They are intended to lower the cost of DNA sequencing beyond what is possible with standard dye terminator methods. NGS has led to overcoming the limitations of conventional DNA sequencing methods and has found usage in a wide range of molecular biology applications (Thompson *et al.,* 2011).

5. Future: Emerging Technologies

The future of DNA and RNA sequencing holds exciting possibilities with the emergence of novel technologies. Third-generation sequencing platforms, such as nanopore sequencing and single-molecule sequencing, promise further improvements in read length, accuracy and cost-effectiveness. Nanopore sequencing, pioneered by companies like Oxford Nanopore Technologies, allows direct, real-time sequencing of DNA and RNA by passing molecules through nanoscale pores. This technology holds great potential for applications in diagnostics, environmental monitoring and point-of-care testing. The integration of sequencing data with other omics technologies, such as proteomics and metabolomics, will provide a holistic understanding of biological systems (Levene *et al.,* 2003). This interdisciplinary approach is crucial for unravelling the complexities of diseases and advancing precision medicine.

6. Conclusion

Biotechnology in aquaculture holds tremendous promise in revolutionizing the sector, offering solutions to many challenges such as sustainable production, disease management and improving fish quality. By integrating advanced genetic techniques, molecular biology and biotechnology, aquaculture can address the increasing demand for seafood while minimizing environmental impacts. Key breakthroughs include selective breeding, genetic engineering, disease-resistant strains and the development of more efficient feeds through bioengineering. Technologies such as gene editing (CRISPR), probiotics and biofloc systems are improving fish growth, health and environmental management, ultimately leading to higher yields and reduced resource usage. However, the adoption of biotechnology in aquaculture faces regulatory, ethical and social challenges, including concerns over genetically modified organisms (GMOs) and the potential impacts on biodiversity. A balanced approach, focusing on transparency and sustainability, is essential to unlocking the full potential of biotechnology in this field. Biotechnology offers a transformative toolset for aquaculture, enabling the industry to meet the growing demand for seafood in a more sustainable, efficient and environmentally friendly manner. With careful management and continued innovation, it can help unlock the potential for a more resilient and prosperous future in aquaculture.

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