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Popular Article

Genetic Engineering in Aquaculture: Progress, Challenges, and Prospects for Enhancing Productivity and Sustainability in the Fisheries Industry

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Abstract

Insufficient aquaculture technologies and low-productivity species fail to meet the global demand for fish. Biotechnology offers a solution by enhancing productivity through genetic engineering. Present article explores the application of genetic engineering in both food and ornamental fishes, detailing various genetic engineering methods. Despite its potential, the adoption of genetic technologies in aquaculture has been gradual. Only a selected few aquacultures organism have been genetically engineered, demonstrating superior performance in captivity. This paper aims to review the current status of genetic engineering in the fisheries industry, providing insights into progress, challenges, and prospects for integrating genetic technologies to enhance productivity and sustainability.

Keywords: Genetic Engineering, Aquaculture, Fish, Genetically Modified Organisms

1. Introduction

The global demand for fish and fish-related products is rising day by day, leading to increased pressure on natural resources and aquaculture production. The escalating demand has strained existing resources, with inefficient culture methods and low-yielding species exacerbating the challenges faced by aquaculture. Despite these challenges, aquaculture serves as a crucial means to meet the surging demand for fish while alleviating pressure on wild-caught stocks.

Genetic and Biotechnology techniques can be used as a tool to produce organisms that are of higher productivity than their natural morphs. Genetic engineering is the modification of the genetic information of living organisms by manipulation of DNA i.e. by adding, removing or repairing part of genetic material (DNA) and changing the phenotype of the organism. Genetic engineering in fisheries has the potential to address various challenges and enhance the efficiency and sustainability of aquaculture. Transgenic fish technology was first introduced in the 1980s and has been used for the genetic improvement of farmed fish (Zhu et al., 1985). The potential applications of genetic engineering in aquaculture are diverse and encompass advancements in breeding programs, the development of transgenic fish with specific genetic traits, and the production of fish with improved nutritional profiles. The production of genetic modified fish is much easier than other organisms due to its high fecundity. Until now, a number of aquaculture organisms have been genetically engineered, showing enhanced performance in captive conditions compared to their wild stock. Salmons, carps, medaka, zebrafish and tilapia are among the examples of genetically engineered animals with superior productivity compared to their non-engineered morphs. Genetically engineered fish serve a multitude of purposes beyond being a source of protein-rich food. They are kept as pets like Glofish and play a valuable role in extracting enzymes for laboratory purposes too.

2. Different methods used to produce GMO

Various methods are employed to produce genetically modified organisms (GMOs). The choice of method depends on the type of organism being modified, the specific genetic modifications desired, and ethical considerations associated with each technique. Here are some common methods used in the production of GMOs:

i. Gene Cloning

Molecular Cloning: This involves isolating a gene of interest and inserting it into a vector (often a plasmid) for replication. The vector is then introduced into a host organism, producing multiple copies of the gene.

ii. Recombinant DNA Technology

This technology allows to isolate, modify, and reinsert specific DNA segments from one organism into the DNA of another, leading to the formation of recombinant DNA.

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iii. CRISPR-Cas9 System

Genome Editing: The CRISPR-Cas9 system allows precise editing of specific genes within an organism's genome. Cas9, guided by RNA molecules, can cut DNA at specific locations, enabling gene insertion, deletion, or modification.

iv. RNA Interference (RNAi)

Gene Silencing: RNAi involves introducing small RNA molecules that can inhibit the expression of specific genes. This technique is often used to study gene function and can be applied to create genetically modified organisms.

v. Biolistic (Gene Gun)

Microscopic particles coated with DNA are shot into target cells using a gene gun. This method is applicable to a variety of organisms, including plants and fungi.

vi. Electroporation

Electric Field Application: Electric pulses are applied to cells, creating temporary pores in the cell membrane through which foreign DNA can enter. This method is commonly used for bacterial and mammalian cell transformation.

vii. Microinjection

Direct DNA Injection: In this method, genetic material is injected directly into the nucleus of a cell using a fine micropipette. This technique is commonly used for creating transgenic animals.

viii. Viral Vectors

Viral Delivery of Genetic Material: Modified viruses, such as retroviruses or adenoviruses, are used as vectors to introduce specific genes into the cells of organisms. This method is often employed in gene therapy.

3. Genetically engineered food fishes:

i. **AquAdvantage Salmon**: In 1989 developed by AquaBounty Technologies, the AquAdvantage Salmon is genetically engineered fish to grow faster than conventional salmon. In 1989, the first AquAdvantage salmon was produced by injecting an Atlantic salmon (*Salmo salar*) egg with a gene construct (opAFP-GHc2) comprising a promoter and termination region from the ocean pout (*Zoarces americanus*) antifreeze gene, along with a growth hormone gene from Chinook salmon (*Oncorhynchus tshawytscha*) (Bodnar, 2010; Clifford, 2014). It’s were the first genetically engineered animal approved for human consumption in United States and Canada (Goldenberg, 2013; Grossman, 2016).

ii. **Tilapia:** Genetic engineering has been applied to tilapia to enhance growth rates, disease resistance, and nutritional content. Hybrid tilapia of *Oreochromis hornorum* were genetically modified using a construct that included the human cytomegalovirus (CMV) promoter connected to tilapia (tiGH) cDNA, along with the polyadenylation site from the SV40 virus by microinjection method (Martínez et al., 1996; Guillén et al., 1999).

iii. **Carp:** Genetic engineering has been employed in common carp to improve traits such as growth and disease resistance (Duan et al., 2013).

iv. **GloFish:** A patented genetically modified zebrafish obtained by incorporating a gene from a jellyfish that codes for green fluorescent protein (GFP) into the zebrafish genome. This genetic modification results in fish that exhibit bright fluorescent colors when exposed to certain wavelengths of light, such as blue light (Gong et al., 2003; Gong et al., 2004).

4. Merits of Genetically Modified Fishes

i. **Enhanced Growth Rates**: Genetic modification can accelerate the growth rates of fish, leading to faster and more efficient aquaculture production. This can contribute to meeting the increasing global demand for seafood.

ii. **Disease Resistance**: Genetic modification can confer resistance to certain diseases in fish, reducing the need for antibiotic use and minimizing the impact of diseases on aquaculture operations.

iii. **Environmental Sustainability:** Genetically modified fish may require less feed to reach market size, contributing to more sustainable aquaculture practices. This can reduce the pressure on wild fish stocks used for fishmeal production.

iv. **Reduced Environmental Impact:** By developing fish that grow more efficiently, there is potential to reduce the environmental footprint of aquaculture, including the amount of land and water required for farming.

5. Challenges of Genetically Modified Fishes

i. **Environmental Concerns**: There are concerns about the potential environmental impact if genetically modified fish escape into the wild. This could lead to ecological disruptions, competition with wild populations, or interbreeding with non-modified species.

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ii. **Unknown Long-Term Effects:** The long-term effects of consuming genetically modified fish are not yet fully understood. Some concerns relate to potential allergens or unintended consequences that may only become apparent over time.

iii. **Ethical and Animal Welfare Concerns:** The genetic modification process may raise ethical concerns related to animal welfare. Questions about the well-being of the modified fish and the potential for unintended suffering may arise.

iv. **Market and Consumer Acceptance:** Consumer acceptance of genetically modified fish products can be a challenge. Concerns about safety, environmental impact, and ethical considerations may lead to resistance or reluctance to adopt these products.

6. Regulations in India

The primary regulatory authority overseeing GMOs in India is the Ministry of Environment, Forest and Climate Change (MoEFCC), through the Genetic Engineering Appraisal Committee (GEAC).

Five authorized bodies are tasked with managing regulations outlined in the Environment Protection Act 1986, specifically the "Rules for Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms/Genetically Engineered Organisms or Cells 1989." These entities include:

1. Institutional Biosafety Committees (IBSC)
2. Genetic Engineering Approval Committee (GEAC)
3. Review Committee of Genetic Manipulation (RCGM)
4. State Biotechnology Coordination Committee (SBCC) and
5. District Level Committee (DLC)

7. Conclusion

The use of genetic engineering in fish farming for increased production and economic gains is contentious. While proponents argue that genetically modified organisms could reduce the environmental impact of aquaculture, concerns arise due to limited understanding of outcomes and potential ecological effects. Most studies, often conducted by producing companies in controlled conditions, neglect environmental fluctuations and use short timeframes, obscuring long-term genetic effects. Although genetically modified fish offer benefits, concerns persist about environmental impact, ecosystem effects, and societal acceptance. Responsible development, rigorous safety assessments, and transparent communication are crucial for ethically advancing

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genetically modified fish technologies. Unrealistic experiments with controversial results highlight the need for a precautionary approach, given substantial gaps in our knowledge of genetic modifications.

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