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Genome Editing Technologies in Catfish: Applications, Prospects, and Challenges for Sustainable Production in Bangladesh

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ABSTRACT

Aquaculture plays a vital role in ensuring food security and economic development in Bangladesh, where catfish farming contributes significantly to both nutrition and livelihoods. However, the sector faces persistent challenges, including slow growth rates, high disease susceptibility, and unreliable reproduction, particularly in indigenous species such as pabda, shing, and magur. Conventional selective breeding approaches have proven insufficient to address these constraints efficiently. In this context, genome editing technologies, especially CRISPR/Cas9, offer a transformative solution for accelerating genetic improvement in catfish aquaculture. This review synthesizes current advancements and applications of genome editing tools, including Zinc Finger Nucleases (ZFNs), TALENs, and CRISPR/Cas9, with a focus on their roles in enhancing growth performance, improving disease resistance, and enabling reproductive control. Targeted modification of genes such as myostatin (MSTN) and MC4R has demonstrated significant potential for improving growth traits, while editing immune-related genes can reduce mortality caused by pathogenic infections. Furthermore, genome editing offers innovative strategies for addressing breeding challenges, including sterility induction and improved hatchery success. Despite its promise, the adoption of genome editing in Bangladesh is constrained by technical limitations, lack of regulatory frameworks, high costs, and socio-ethical concerns. Addressing these barriers requires strategic investment in research infrastructure, capacity building, and policy development. Overall, genome editing holds considerable potential to enhance productivity, sustainability, and resilience in the Bangladeshi catfish aquaculture sector, provided that scientific, regulatory, and societal challenges are effectively managed.

Keywords: Catfish, Genome editing, Growth enhancement, future roadmap, Bangladesh

1 | Introduction

Aquaculture is a critical pillar of food security and economic development in Bangladesh, a nation endowed with extensive aquatic resources (Belton et al., 2011). Catfish aquaculture makes a significant economic and nutritional contribution to Bangladesh. The most common species farmed of the striped or sutchi catfish, Pangasianodon hypophthalmus (Ali et al., 2013 & Ahmed et al., 2010), has a major aquaculture activity in Bangladesh. Catfish species, including Pabda (Ompok pabda) and Shing (Heteropneustes fossilis), are also popular and economically viable in Bangladesh (Arifa et al., 2022). Like indigenous species, the culture of the African magur (Clarias gariepinus) is also popular in different regions of Bangladesh (Rahman et al., 1992).

Aquaculture plays an important role in the food supply, accounting for more than 57% of aquatic animal foods (FAO, 2022). The long-term growth and expansion of the aquaculture industry depends on protein-rich food products to meet the needs of the growing global population. In response to population growth, the aquaculture sector seems to offer an effective solution (Hsu et al., 2014). This progress is largely the result of relentless efforts by researchers in advanced genetic engineering, particularly through the use of CRISPR/Cas9 technology across various fish species (Billion et al., 2017). Specifically, to enhance desirable traits, CRISPR/Cas9 is a groundbreaking genetic engineering tool that enables precise, targeted modifications to fish DNA (Adli et al., 2018). As such, this technology surpasses traditional breeding techniques, offering a cheaper, easier, and more precise method for genetic improvement (Jao et al., 2013; Hwang et al., 2013; Ferdous et al., 2022; Roy et al., 2022).

Genome editing enables improvement of key traits such as growth performance (body weight, length, muscle development), muscle quality, disease resistance, and sex control (Li et al., 2014). Additionally, to enhance disease resistance in fish by targeting immune-related genes or pathogen recognition pathways, thereby reducing reliance on antibiotics and chemical treatments, CRISPR/Cas9 technology offers a promising solution (Jao et al., 2013). Moreover, by genetically enhancing key characteristics of fish species, this technology has revolutionized modern aquaculture. For example, Scientists have successfully eliminated germ cells in Atlantic salmon (Wargelius, 2016), improved feed conversion efficiency in yellow catfish (Zhang et al., 2018), efficiently induced gene mutations in Tilapia, and minimized off-target effects (Yu et al., 2019).

However, conventional selective breeding is slow in addressing major challenges such as disease outbreaks, slow growth, and reproductive failure. In response to these constraints, this review synthesizes current and potential applications of genome editing technologies in catfish aquaculture, focusing on disease resistance, growth enhancement, and reproductive control. Furthermore, it evaluates technical efficiencies, highlights challenges for commercialization, and identifies research gaps relevant to Bangladesh.

2 | Status of Catfish Aquaculture in Bangladesh

In Bangladesh, catfish aquaculture is a dynamic but challenging sector of the country's fisheries output. Farming of pangasius dominates commercial production, though primarily for export (Nguyen et al., 2018), while magur, shing, and pabda are highly valued in domestic markets for their nutritional and taste qualities, often commanding premium prices. However, the extent of aquaculture is severely hampered by systemic bottlenecks. Key indigenous species like magur and pabda are notoriously slow-growing (Chakrabarti et al., 2012), requiring 7-10 months to reach marketable size, thereby extending production, operational costs and risks. In early stages of disease, outbreaks cause devastating mortality rates of 55-75%, frequently attributed to microorganisms such as Aeromonas hydrophila and Edwardsiella ictaluri (Admasu et al., 2018). For several indigenous species, the critical constraint is the consistent failure in controlled breeding. Most farmers rely on fry from wild stocks, which is unsustainable and unreliable for natural stocks (Can et al., 2025). In hatcheries, gulsha and shing suffer from low fertilization and hatching rates, often below 45%, which creates a shortage of quality seed. These integrated challenges make slow growth, high disease susceptibility, and unreliable reproduction stifle productivity and undermine the sector's potential contribution to economic growth and food security. To create a clear demand for disruptive technological solutions, such as genome editing, to address these acute problems with the required urgency.

3 | Types of Genome Editing Technologies used in Catfish

Genome editing is a transformative tool for aquaculture. To ensure sustainable fish production, it is important to adopt this innovative method. Specifically, genome editing has a considerable economic impact in aquaculture (Yang et al., 2025) and has been employed to address critical issues such as development, reproduction, growth, and disease resistance (Blix et al., 2021). For example, sustaining reproduction in channel catfish (Ictalurus punctatus) through hormone therapy and manipulation of the gonadotropin-releasing hormone gene is essential (Qin et al., 2022); furthermore, targeting the Follicle-Stimulating Hormone gene enables effective sterilization (Qin et al., 2023). In addition, editing genomic DNA in channel catfish via artificial fertilization utilizes the CRISPR/Cas9 system (Elaswad et al., 2018). The myostatin (MSTN) gene also modulates skeletal muscle growth, thus improving growth and productivity in channel catfish (Khalil et al., 2017). Altogether, to enhance aquaculture performance and key traits, it is imperative to leverage advanced genomic resources and tools and thus drive progress in catfish broodstock (Jin et al., 2016).

Zinc Finger Nucleases (ZFNs)

Zinc finger nucleases are a robust tool for genetic engineering in organisms like Drosophila, rats and zebrafish (Remy et al., 2010). Qin et al. (2016) applied modified ZFN technology with electroporation to sterilize channel catfish, achieving a mutation rate of about 19.7%. On the other hand, Dong et al. (2011) engineered ZFNs in fish to study the elusive function of MSTN, creating a strain of yellow catfish with increased muscle mass.

In addition, Zhu et al. (2011) mediated ZFN germline gene inactivation in zebrafish, focusing on its utility as a specific reverse genetic strategy. While powerful, ZFNs have been largely superseded by newer technologies due to their high cost and complexity.

Transcription Activator-Like Effector Nucleases (TALENs)

Transcription activator-like effector nucleases are a powerful genome editing technology applicable across diverse organisms and cell types (Sun & Zhao, 2013). The site-specific double-strand breaks introduced by TALENs significantly increase the efficiency of genomic modification. Ansai et al. (2013) demonstrated efficient targeted mutagenesis in medaka (Oryzias latipes), establishing it as a model for genetics and genomics. In catfish, Qin et al. (2023) used modified TALEN technology with electroporation to edit the Follicle-Stimulating Hormone gene for sterilization purposes. TALENs offer high specificity but share the same drawbacks as ZFNs regarding protein engineering complexity.

CRISPR/Cas9

The Clustered Regularly Interspaced Short Palindromic Repeats-associated protein 9 (CRISPR/Cas9) system has been widely adopted for directed mutagenesis in plants and animals (Dehler et al., 2016). Aich et al. (2023) noted that CRISPR-Cas9 allows efficient and targeted enhancement of aquaculture traits, providing solutions to many industry problems. Zhu et al. (2024) highlighted its use in improving desirable fish traits for sustainable aquaculture. It is a powerful tool for studying gene function in medaka fish cells (Liu et al., 2018) and has proven highly efficient for editing the channel catfish genome (Khalil et al., 2017). For instance, gene-edited MC4R channel catfish show beneficial traits for commercial farming (Coogan et al., 2022). This approach holds great promise for producing growth-enhanced catfish and increasing productivity in Bangladesh due to its relative simplicity, high efficiency, and lower cost.

4 | Effects of Genome Editing Technology in Catfish Aquaculture

In the world, genome editing technology represents an advanced tool for addressing the core constraints in catfish aquaculture. The effects and impacts of it are focused on three critical areas: disease resistance (Wang et al., 2024), growth enhancement, and reproductive control. In disease resistance, targeted editing of immune-related genes, such as toll-like receptors or encoding antimicrobial peptides, can improve innate immunity, basically reducing mortality from devastating pathogens and offering a sustainable alternative to prophylactic antibiotic use. For growth enhancement, the application of the myostatin (MSTN) gene (Coogan et al., 2021) has proven highly effective, which increases 20-40% in body mass in channel catfish by promoting hyper-muscularity; on the other hand, editing appetite-regulating genes like MC4R can increase the efficiency of feed. In reproductive control systems, genome editing offers solutions to chronic breeding problems; it can induce sterility to prevent unwanted maturation in farming ponds or to produce monosex populations for species with sex-dependent growth (Budd et al., 2015). Moreover, editing genes involved in gonadotropin-releasing hormone or egg quality can improve fertilization and hatch rate success in hatcheries, and overcome the seed shortage that plagues the sector. In addition, gene technology enables the creation of gene drives and precise knock-in models, allowing the introduction of desirable traits and beneficial alleles into populations, thus providing a strategic genetic tool for rapid trait improvement (Moran et al., 2024).

5 | Prospect of Genome Editing in Catfish Aquaculture of Bangladesh

In catfish aquaculture sector, genome editing technology offers a significant opportunity to directly address its most pressing constraints. This advanced tool offers the potential to develop catfish lines with enhanced disease resistance, dramatically accelerated growth rates by targeting genes such as myostatin, and reliable reproductive performance. Bangladeshi entrepreneurs struggling with slow-growing catfish species like tengra, magur, boal and pabda and with high nursery mortality, could see genome editing catalyze climate-resilient, high-yielding production. Thinking about it, this potential requires strategic investment in research capacity to adapt these technologies to indigenous species, as well as the establishment of a science-based regulatory framework. Finally, genome editing can strengthen food security, boost export competitiveness, and safeguard the livelihoods of millions dependent on this important catfish industry.

6 | Challenges and Limitations

Though this gene has transformative potential in aquaculture, the system for deploying genome-edited catfish in Bangladesh is fraught with significant challenges, including manpower and logistical limitations. Technical manpower difficulties include the need to optimize editing of the gene of interest, as the tough chorion of catfish eggs complicates microinjection, and the need to determine and minimize off-target effects. The biological complexity of growth and immune resistance requires advanced gene-editing strategies that are still developing. The main obstacle is the absence of a science-based regulatory framework in Bangladesh to govern the gene editing for breeding and commercialization of the genome-edited aquaculture sector, creating uncertainty for teachers, researchers and entrepreneurs. Social and ethical acceptance cannot be overlooked, as public perception of genetically modified food products requires special management through communication and demonstrable benefits. In addition, laboratory facilities, funding and infrastructure barriers exist, including the high cost of maintaining advanced genome-editing core facilities and a lack of trained bioinformatics personnel within the university and national research institutions. Finally, strategic environmental risk assessments are imperative to assess the potential ecological consequences, such as the impact of edited individuals on wild gene pools, before any commercial release is considered.

7 | Future Directions

To translate the promise of genome editing into tangible benefits for Bangladeshi catfish aquaculture, a coordinated and strategic research and policy agenda (Garden et al., 2018) must be pursued. Priority must be given to infrastructure capacity through the establishment of a dedicated research lab, and intensive training programs must be arranged to build expertise in functional genomics and gene editing practice. Besides that, preparing high-quality reference genomes for key commercially important aquaculture species such as tilapia, magur, shing, pangas, and pabda is essential to assess the effectiveness of the target gene. Primary research should focus on one or two high-impact traits, like MSTN knockout for growth or GnRH editing for reproduction, to build confidence and demonstrate viability. Moreover, teachers, scientists and farm stakeholders must proactively engage with policymakers to develop a risk-proportionate regulatory pathway that differentiates between transgenic organisms and natural mutations. Emphasis on identifying next-generation precision tools, such as base and prime editing, should be integrated into long-term plans. Finally, genome editing needs to be framed not as an alternative but as a powerful technique that builds on old selective breeding programs. In a nutshell, Livelihood studies on market acceptance, supply chain impacts, and cost-benefit analyses are needed to guide responsible commercialization, ensuring the technology is ultimately useful for farmers and consumers while safeguarding the environment.

8 | Conclusion

In Bangladesh, Catfish aquaculture is more preferable and economically viable to farmers. Genome editing technologies offer a new opportunity for the Bangladeshi catfish aquaculture sector. By applying this, the critical bottlenecks of slow growth, disease susceptibility, and reproductive inefficiency can be addressed, and these tools can catalyze the development of superior, climate-resilient breeds. The technique has the potential to improve food security, increase export earnings, and support millions of farmers and entrepreneurs. However, opening this potential requires a concerted effort that integrates comprehensive investment in local research and development with the establishment of a supportive, science-based policy environment. With ethical considerations, inclusive dialogue and careful planning, Bangladesh can position itself at the forefront of applying genome-editing technology to the sustainable catfish sector.

Author Contributions

Md Saiful Islam: Conceptualization, data collection, data analysis, interpretation, manuscript writing, and editing. Md. Amdadul Haque: Conceptualization, data collection, data analysis, manuscript writing, and editing. Al-Amin: data collection and data analysis. Md. Moniruzzaman: data collection and data analysis. Farjana Jannat Akhi: data collection and data analysis, and Mohammad Ashraful Alam: manuscript writing and editing. All authors have read and approved the final published article.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All data generated and analyzed during this study are included within the manuscript. No additional datasets are available.

Ethics Statement

Not applicable.

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