The Next Wave of Aquaculture: Genomic Tools for Fish and Shrimp Improvement

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ABSTRACT

Selective breeding is important to improving aquaculture species growth rate, illness resilience, and reproduction ability. Genetic improvement attempts on shrimp, tilapia, Indian major carps, rainbow trout, and Atlantic salmon have generated measurable genetic progress. With more precise technologies like genomic selection and molecular markers such as SNPs and QTLs coming into existence, the much-maligned breeding results hold more accuracy. The threats to genetic diversity with inbreeding and biosecurity concerns remain real and even more critical in aquatic settings. Barraged by environmental threats and technological constraints, shrimp breeding is far from a potent application. Recent innovations such as feed optimisation and CRISPR-Cas9 are delineating our future strategies. The avenue widening for scientific intervention in aquaculture stands to greatly enhance food security and sustainability, and maintain cultured species' genetic integrity and commercial value.

INTRODUCTION

Selective breeding has become highly necessary, partly due to the rising demand for quality aquatic goods, especially since fish and shellfish are an important cause of pressure on aquaculture worldwide. Systematic breeding programs must increase growth, survival, and feed efficiency rates and develop disease resistance. All these traits should be considered in the light of inheritance and genetic variability. Strong selection indices and organised breeding stations should be employed for long-term profitability. National breeding efforts have shown that genetic improvement has been achieved in commercially important species. WorldFish and ICAR-CIFA have such advances. While the industry progresses, juxtaposing classical techniques with modern biotechnology would provide a bright future in increasing sustainability, productivity, and food security worldwide.

CRITERIA FOR SELECTING COMMERCIALLY IMPORTANT TRAITS

Breeding objectives must be precisely established before selection programs may begin. Growth rate, meat quality, disease resistance, food conversion efficiency, and maturation age are characteristics of considerable economic value in most species. Standard deviation and heritability estimates for significant traits in several species are provided. It is determined that due to high fecundity, which enables strong selection, and large genetic diversity, the prospects for improvement by selection are especially favourable for growth rate and age at maturation. A slower selection response is anticipated since meat quality and disease resistance have relatively modest genetic variance. A review of sixteen selection experiments is conducted. In trials 12 and 4, selection was done based on disease resistance and growth rate. Fifteen of these tests yielded a good result. These responses to selection substantially support the idea that fish benefit from the possibility of genetic improvement. The most effective selection programs are those that blend individual and family merits.

SPECIES-WISE SELECTIVE BREEDING PROGRAMS

Selective breeding has been widely used to improve desired features like growth rate, disease resistance, and survival in several commercially significant aquaculture species. Long-term salmon breeding projects, concentrating on growth, sea lice resistance, and early maturation features, were initiated in Norway in the late 1960s, especially for Atlantic salmon (*Salmo salar*). Selective techniques such as combined individual and family selection were used effectively. Similarly, rainbow trout breeding demonstrated enhanced early maturity and flesh quality features using stress response and image analysis approaches. The GIFT strain of tilapia was developed in 1988 under the direction of ICLARM (now WorldFish) projects, and it showed growth improvement of up to 88% over five generations. Because of their rapid development and flexibility, Nile tilapia were chosen, and breeding projects are currently being conducted in Africa. In 1992, ICAR-CIFA started the first breeding effort for Indian major carps, particularly *Labeo rohita*. This program produced the "Jayanti Rohu" strain, which had a 17% genetic gain in growth. Data were gathered and described using phenotypic and molecular techniques to create base populations for Catla strains. For practical improvement in traits such as growth, survival, and tolerance to cold, some countries have taken an initiative in hybridisation and pure line development of common carp, Chinese, Indian, and Israeli. Lastly, AAKVAFORSK encouraged the breeding of Mrigal (*Cirrhinus mrigala*) in Vietnam, emphasising genetic improvement and sustainable seed supply. Those international collaborative scientific endeavours of aquaculture genetics are the projects dealing with developing sustainable productivity.

GENETIC TOOLS AND MOLECULAR MARKERS

Molecular markers directly reflect genetic variations at the DNA level. Due to these reasons, such markers can be used for population structure determination or population attributes of commercial importance, among other uses, for example, gene identification and cloning, genetic mapping, genetic relationship analysis, heterosis prediction, and molecularly assisted selection breeding. Some of the molecular markers are DNA amplification fingerprinting (DAF), random amplified polymorphic DNA (RAPD), single-nucleotide polymorphisms (SNP), amplified fragment length polymorphism (AFLP), inter-simple sequence repeat (ISSR), simple sequence repeat (SSR), single-strand conformation polymorphism (SSCP), restriction fragment length polymorphism (RFLP), sequenced characterized amplified region marker (SCAR), etc. It is possible to use genetic techniques to enhance characteristics like growth, disease resistance, flesh colour, and stress tolerance, which are hard to quantify (Rasal and Sundaray, 2020). Using molecular markers in breeding has improved the precision and effectiveness of selecting specific traits. Therefore, the aquaculture industry continues to adopt technologies like breeding assistance at the molecular level, such as selective breeding of genomes. The sequencing recently concluded includes rainbow trout, Atlantic salmon (*Salmo salar*), bass (*Dicentrarchus labrax*), medaka (*Oryzias latipes*), pufferfish (*Takifugu rubripes*), green pufferfish (*Tetraodon nigroviridis*), Nile tilapia (*Oreochromis niloticus*), channel catfish (*Ictalurus punctatus*), zebrafish *(Danio rerio*), and Atlantic cod (*Gadus morhua*). There are many possibilities for advanced fundamental research and commercially applicable products that arise from the availability of genetic information. One could cite the building of genetic linkage maps and investigating the associations of molecular genetic markers. DNA markers are also designed for assisted breeding technology through quantitative trait loci.

ROLE OF GENOMIC SELECTION IN MODERN BREEDING PROGRAMS

Genomic Selection uses various genetic markers to forecast an individual's breeding value depending on their genotype. The most popular method for achieving this high level of genome coverage is the Single Nucleotide Polymorphism (SNP) array. When phenotypes are documented on the relatives of the candidate breeders, GS is especially important when it comes to fatal features that cannot be recorded on living individuals, such as illness and parasite resistance, temperature and salinity tolerance, fillet quality, and yield (Gebreyesus *et al.,* 2020). In contrast with traditional selective breeding, MAS is especially helpful for indirect selection of economically significant qualities, including disease resistance, fillet quality, feed efficiency, sexual maturation, and fecundity, which are hard to measure, have poor heritability, and necessitate destructive sampling of breeding candidates. By selecting before maturity, this breeding approach may speed up the selection process, increase accuracy, and shorten the generation gap. Selecting for disease resistance features based on genetic markers would lower challenge test expenses, avoid losing useful genotypes during the test, and lessen the detrimental effects of selection on other traits, for several aquaculture species, including Nile tilapia, rainbow trout, Half-smooth tongue sole, common carp, Indian major carp, Catla, yellowtail, Atlantic salmon, channel catfish, and black tiger shrimp, Penaeus monodon, crucial causal genes governing sex determination have been found even though it is a complex trait. The sex determination region (SDR) is more dependable for sex control in Nile and blue tilapia after five strains were resequenced using TGS (Tao *et al*., 2021).

CHALLENGES AND LIMITATIONS

Selective breeding programs, in the case of fish and shrimp, have permitted significant genetic advances, especially in growth. Typically, the modifications are made for a handful of generations only; otherwise, there is much potential for developing key economically important traits. This is mainly due to the absence of reliable phenotyping and recording systems, especially for expensive or difficult measure traits such as disease resistance, reproductive success, or efficiency in feed use. For instance, creating family-based breeding programs in shrimp while reducing inbreeding and preserving genetic variety is one of the biggest hurdles. In communal upbringing, family assignment is necessary to estimate genetic parameters and breeding values and to prevent the large expenses of physical tagging. Furthermore, compared to terrestrial livestock, the aquatic environment slows the rate of gene advancement due to technical challenges with mating management, pedigree tracking, and reliable trait measurement. Other significant obstacles include the possibility of reducing the gene pool as a result of using elite broodstock repeatedly and genotype–environment interactions, where animals chosen in controlled settings might not perform similarly under changing farm conditions. Deliberate viral exposure of fish in aquatic hatcheries for selection, especially for disease resistance screening, is one of the major challenges facing biosecurity during the selection of the animals.

FUTURE PROSPECTS AND INNOVATIONS

Innovation in fish breeding

The development of hybrid, ploidy, cell nuclear transfer, chromosomal engineering, and genetic engineering technologies proves that tremendous progress has been made after years of work. These initiatives have greatly increased the aquaculture sector's productivity and the fish's genetic diversity. There are, however, only a few species of the main farmed fish. One of the main causes is insufficient interaction between the fundamental study of fish genetic breeding and the actual breeding procedures. Another matter is swiftly integrating these new technologies into genetic breeding procedures. Furthermore, it has been demonstrated that traditional cellular engineering techniques like artificial gynogenesis and remote hybridisation work well. However, the need for favourable conditions and rigorous genetic breeding detection methods limits the number of new kinds that may be produced using these approaches. Hopefully, the problems above will be addressed, and focused research will continue with persistent, long-term efforts. Therefore, it is necessary to integrate genetic breeding techniques into the market and connect basic research with industry requirements. An innovative environment must also be promoted to speed up the creation of new technologies. Fish DNA may be accurately altered by a genome editing process called CRISPR-Cas9, which improves growth rates, disease resistance, and selective breeding.

Innovation in Shrimp Breeding

It has been seen that several new breeding technologies are becoming pretty popular in aquaculture (especially in shrimp farming) to deal with a lot of issues. These breeding techniques should minimise adverse impacts on the environment from a shrimp's point of view and enhance its growth and disease resistance. Among these innovations are selective breeding initiatives. These programs concentrate on characteristics in shrimp populations, such as growth rate and disease resistance, to produce broodstock that can produce offspring with desirable properties. In shrimp farming, selective breeding successfully enhances commercially significant qualities, including growth and disease resistance. The widespread use of genetic enhancement techniques is, nevertheless, severely hampered. The breeding technique is genetic alteration. This method presents ethical and environmental issues, even though it may be able to build shrimp with better features. Numerous scientific and social groups continue vigorously discussing crop improvement using genetic engineering and genetic modification to create new types suitable for organic agriculture. The primary worry is the potential for unforeseen consequences on global and human health. Shrimp feed innovations are intended to improve the nutritional value of the shrimp produced and lessen dependency on wild-caught fish for feed. For example, fish fingerlings may become stunted if raised at a higher stocking density and fed natural food for a longer period. To increase growth, farmers add soybean meal, rice bran, fish meal, and groundnut oil cake to the feed (Pathan *et al.,* 2022).

CONCLUSION

Selective breeding has catalysed aquaculture's much-needed solutions for the long term in improving important traits to meet the increasing needs of international seafood markets. Species-focused programs and molecular tools have benefited much from the latest advances. However, there is still much weighing down the full potential of genetics, especially in complex environments such as shrimp farming. Knowledge seems to have filled up in basic research and commercial breeding operations. The future will depend on how new technologies enhance scalable breeding programs, like genomic selection, CRISPR-Cas9, and molecular diagnostics. More will be produced while maintaining the health of ecosystems and the diversity of genes within them. For successful long-term implementation, coordination of international programs, continuous innovation, and legislation that supports ethical, efficient, and effective breeding systems for shrimp and fish species must be married.

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