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Outbreeding, Crossbreeding, Utilization of Heterotic Effect

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Abstract

The many outbreeding techniques, including line breeding, crossbreeding and graded upbreeding, are crucial for enhancing genetic diversity, growth performance and disease resistance in aquaculture species. The importance of hybrid vigor or heterosis, in the success of outbreeding could be aptly illustrated by the superior growth of hybrids, such as crossbreds of common carp (*Cyprinus carpio*), in early life history. Crossbreeding techniques like two-way, three-way and rotational crossings increase fish stocks' productivity and flexibility. Multiple studies on Atlantic salmon show that outbreeding frequently increases the likelihood of outbreeding depression when it impedes local adaptation. In Asia, genetic enhancement activities have surged for species such as the giant freshwater prawn, tilapia and carp. However, the adoption has been constrained by economic and technological factors. Future aquaculture breeding programs must successfully include genomics and multi-omics techniques.

Keywords: Crossbreeding, Genetic improvement, Heterosis, Outbreeding depression

Introduction

Outbreeding is a breeding strategy in genetics that involves crossbreeding animals that have no genetic ties to increase human desire to produce impersonal output performance from these animals. To incorporate desirable, unique characteristics from various strains or breeds for quicker growth, higher survival rates and superior disease resistance, outbreeding is done in fish breeding by hybridisation or crossbreeding. Crossbreeding is crucial for creating high-yielding fish stocks accustomed to various habitats. Hybrid vigour or heterosis, the greatest advantage of breeding systems of this nature, is exhibited in the progeny of crossbreds that outperform their parental stock. This is particularly relevant to tilapia and common carp, where the cross-fertilised young fish generally exhibit improved growth and robustness in their formative early life stages. Heterosis is recognised as a critical component of several selective breeding programs for strong and high-yielding fish strains due to the fast growth of aquaculture in supplying the demand for food worldwide. All outbreeding methods, along with heterosis, crossbreeding tactics, related dangers and aquaculture applications, are described in this article.

Types of Outbreeding

Graded Upbreeding

Graded upbreeding is an outbreeding approach whereby the lesser-performing breed is slowly infused with genes of the higher-performing breed. In fisheries, graded upbreeding could enhance fish stocks' growth rate, disease resistance, or other characteristics. This mechanism minimises the hazards accompanying an abrupt and sudden change in genetics.

Crossbreeding

Crossing of two different breeds of the same animal produces new breeds. One common example is breeding fast-growing species with disease-resistant ones to produce offspring with both characteristics. This method is more frequently used in creating hybrid species, which are known to outperform the parental lines, because it has proven to be highly beneficial in the development of bred fishes (Huang *et al.*, 2023).

Line Breeding

Line breeding consists of outbreeding with individuals from the same breed but without common ancestors within a few generations. The line breeding method in fisheries enhances fish populations' genetic fitness and diversity and

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reduces inbreeding depression. By line breeding, fisheries can produce fish stocks that are healthier and more resilient.

Heterosis and Effects

Heterosis or hybrid vigour is defined as genetic variation and the production of hybrid offspring that exhibit higher fitness and performance. In aquaculture, this phenomenon is hailed as especially beneficial. The degree of heterosis varies, though and some hybrids have less noticeable advantages, especially in situations that are uncertain or changeable (Wang *et al.*, 2023). Crossing between two homozygous individuals for many contrasting genes would provide highly heterozygous progeny; most of their genes would be heterozygous. Comparison between the offspring and their parents could lead to higher phenotypic expression in the progeny; this superior expression is termed heterosis. The study attempts to check the phenomenon of heterosis, or hybrid vigour, in common carp (*Cyprinus carpio*) by comparing the growth performance of crossbred carp with that of their parental strains. Fast growth in crossbred carp showed heterosis compared to the faster-growing parent, especially in juvenile stages during the first summer. However, this effect diminished in winter and during the adult stages. Heterosis was often expressed when crossing strains from different geographic origins, *e.g.*, Chinese and European races. Under mixed or stressful environments, growth increased dramatically. The Dor-70 strain was found to grow equally well, if not better, than any of the crossbred fish. Thus it is being used as a parent to diminish the hybrid effects. Heterosis could enhance growth, survival and disease resistance in aquaculture; however, the extent to which it would help will depend on the environment, genetics and age of the fish. Heterosis is a situationally important tool for the enhancement of common carp production.

Cross-Breeding Strategies

Crossbreeding in fish is one of the basic procedures to improve desirable traits like growth rate, disease resistance and adaptability, which can be done in two or three ways. Two-way cross-breeding means that two different species or strains are mated. In contrast, three-way cross-breeding involves three different organisms, allowing more beneficial traits from multiple genetic backgrounds to enter the population. These methods have been adopted as part of fish breeding programs to produce improved quality and quantity of fish stocks to contend with increased market demand in aquaculture. Such crossbreeding strategies also enhance aquaculture's sustainability and productivity by increasing genetic diversity and reducing inbreeding. Of course, selective breeding with two- and three-way crossbreeding aims to produce offspring that exhibit improved fitness attributes in compliance with all other components of fish breeding programs.

Rotational crossbreeding is one of the most important methods of increasing the genetic diversity among fish populations while improving the health status of these populations at fish farms. This method gets fish with different genetic lineages into the breed to obtain offspring with favourable traits, such as enhanced growth rates and disease resistance, the two fundamental qualities of any sustainable aquaculture practice. Genetic improvement programs aim to identify and select fish that possess these traits to accelerate the development of highly performing strains. Selective breeding, which is part of rotational crossbreeding, further focuses the breeding process on desirable attributes of the fish. Aquaculture genetics develops the theory needed to understand the genetic basis of such traits involved in enabling better breeding programs.

Risk and Limitations

Outbreeding Depression

Minimising divergence at these ostensibly adaptive loci can lower the incidence of outbreeding depression (Fitzpatrick and Funk, 2019). Adaptive loci are particular sites on the genome associated with traits that confer improved viability or reproductive success to organisms in a particular environment. These loci are of course shaped by natural selection and thus show genetic differences between populations that are diverging into different environmental conditions. Identification of adaptive loci aids researchers in deciphering evolutionary adaptiveness and response of species to environmental challenges. The risk of outbreeding depression in endangered Atlantic salmon by evaluating first- and second-generation outbreed cross types across three river populations using reciprocal transplant experiments. While most comparisons showed little evidence of outbreeding depression due to genetic incompatibilities, there was a notable trend in the ECO population where outbreed individuals showed lower survival relative to pure types, likely indicating a loss of local adaptation. This effect was supported by positive correlations between recapture rates and the percentage of local genes in the outbreed fish, though these results were not consistently statistically significant.

Applications

Formal genetic improvement programmes have been established for carp, tilapia and Giant freshwater prawn in several Asian countries. Carp is the most important freshwater fish, contributing about 41.6% to world aquaculture production. Various carp species are farmed extensively in many South and Southeast Asian countries. Selective breeding programs have been initiated for important species in Bangladesh and Thailand; these include silver barb (*Puntius gonionotus*), rohu (*Labeo rohita*) in India and common carp (*Cyprinus carpio*) in China, Indonesia and Vietnam. After carp, the most important freshwater fish is tilapia and several improved strains of tilapia have been developed by national aquaculture institutions in Asia. The genetically improved farmed tilapia (GIFT) strain has involved major international and regional efforts by the WorldFish Centre and Norwegian, Philippine and Malaysian institutions. Genetic improvement of the giant freshwater prawn (GFP) (*M. rosenbergii*) was only initiated in 2007, after the successes of breeding genetically improved strains of farmed tilapia and carp became better known. GFP is one of the most important crustaceans in inland aquaculture in the (sub) tropics and fits in well with the typical Asian smallholders' system of prawn polyculture along with carp or tilapia. Selective breeding has been started in China, India and Vietnam. The main aim of such programmes is to develop high-yielding strains with good adaptation and high survival rates under Asian culture conditions. Increasing awareness and conducting routine visual inspections and genetic analyses utilising GIFT-specific molecular markers will aid in preventing the unlawful movement of GIFT to unapproved locations. The general design of experiments on tilapia is illustrated in figure 1; however, it is often modified according to the biological and production cycles of the species. Briefly, a hierarchical nested or partial factorial mating design (for example, one male mated to two females) generates 50-100 full and half-sib families per generation.

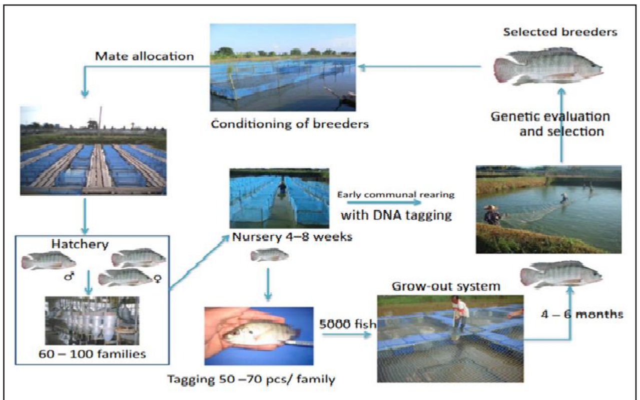

Figure 1: Blueprint for genetic development programmes in aquaculture farming (Nguyen, 2016)

Upon harvest, body metrics from tilapia are recorded in addition to important characteristics such as sexual maturity and survival. After data collection, BLUP is used to evaluate the genetic merits or estimated breeding values (EBVs) of each pedigree member. The welfare of the species will be determined by the EBV, whereby the fish with the highest EBVs form the new parental generation.

Future Prospects

Aquaculture fish and shellfish breeding are changing due to genomic techniques, including genomic editing and marker-assisted selection (MAS). Breeders can look for and identify genetic markers linked to significant economic qualities, including growth, feed efficiency, reproduction and disease resistance, by using these molecular techniques (Du *et al.*, 2021). Despite advancements in molecular genetics, genomics and bioinformatics, their application in genetic improvement of aquaculture species in Asia has been limited, with DNA markers mostly used for population characterisation and biodiversity rather than selective breeding. Although genetic linkage mapping and QTL identification have been developed, technical and economic constraints such as limited markers, low marker effects, high genotyping costs and inconsistent marker QTL associations hinder the broader application of MAS. Only two MAS applications have been reported in aquaculture: IPN resistance in Atlantic salmon and lymphocystis resistance in Japanese flounder. In contrast, genomic selection, already successful in dairy cattle, is emerging as a powerful tool. However, its adoption in aquaculture is limited by a lack of pedigreed populations, phenotypic data and SNP chips. Nevertheless, simulations indicate that genomic selection can bring fairer genetic gain and a decrease in inbreeding. In aquaculture breeding, metagenomics and omics integration also allows for broodstock selection more accurately through an analysis of the host genetics, gene expression and its microbiome to study the interaction with traits like growth, disease resistance and stress tolerance. This comprehensive approach would yield productive, healthy and environmentally sustainable farmed species. The future development will depend upon cheaper genotyping, better data collection systems and long-term stakeholder investment in the scheme. Besides, approaches such as metagenomic prediction and integrating different omics data (transcriptomics, proteomics and metabolomics) into systems biology will help unravel complex traits for the benefit of breeding.

Conclusion

Outcrossing becomes a powerful tool in genetics by improving aquaculture through hybrid vigour, resistance and genetic diversity. Many productive strains of common aquaculture species, including carp, tilapia and giant freshwater prawns, have been achieved by applying graded upbreeding, crossbreeding and line breeding techniques. Thus, a practitioner must consider the pros and cons of outbreeding against outbreeding depression effects for strong local adaptations. Poor infrastructure, low prices and a lack of information on Asian aquaculture restrict the advancement of molecular techniques such as genome and marker-assisted selection. With the availability of genomic tools and modern technologies such as metagenomics and systems biology, rehabilitation and investments in data systems is the way forward for breeding fish. This system should safeguard strong aquaculture against the ever-increasing demand for aquafeeds through stringent control of inbreeding and accelerated improvement of traits.

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