



Selective Breeding: How DNA Markers Are Transforming Aquaculture Breeding?

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Selective breeding using molecular markers is improving aquaculture productivity by enabling the precise selection of superior broodstock. Case studies on Atlantic salmon and Rohu demonstrate significant gains in disease resistance and growth. Similar advances in scampi and shrimp culminate in improved survival and production stability. Therefore, genetic selection offers a reliable way to improve performance and sustainability in aquaculture in less time.

Introduction

Fish have become one of the fastest-growing sources of animal protein in the world. From salmon farms in Norway to carp ponds in India, aquaculture now feeds billions. But behind this success lies a persistent challenge: how do we produce faster-growing, disease-resistant, and high-quality fish without waiting for generations? Traditionally, farmers selected the “best-looking” fish, those that grew faster or survived diseases. But this method is slow and often unreliable. Today, science offers a smarter solution: selecting fish based on their DNA. Every fish carries a set of instructions in its DNA that determines how it grows, survives, and responds to environmental stress. Scientists have discovered that certain small regions in this DNA, known as molecular markers, are closely associated with desirable traits. These markers act like biological indicators or “flags” that help identify superior fish at a very early stage, even before the traits are physically expressed.

What Are Molecular Markers?

Think of molecular markers as **genetic barcodes** hidden inside the DNA of fish and shellfish. These markers are linked to important traits such as growth rate, Disease resistance, Stress tolerance, and flesh quality. Instead of waiting months or years to observe these traits, scientists can now detect them early, sometimes even at the larval stage. This approach is called **Marker-Assisted Selection (MAS)**. In simple terms: If a DNA marker is linked to a “good trait,” selecting fish with that marker increases the chances of getting better offspring. MAS works by identifying markers associated with Quantitative Trait Loci (QTLs), regions of the genome that control important traits. Once identified, these markers can be used to select superior broodstock more efficiently.

Why Molecular Markers Matter in Aquaculture?

The use of molecular markers is not just a scientific advancement; it is a practical game-changer.

Key advantages:

- ✓ Early selection (before traits are visible)
- ✓ Higher accuracy than traditional breeding
- ✓ Faster genetic improvement

- ✓ Better disease management
- ✓ Reduced production losses

Traditional breeding may take many generations to improve traits, but MAS can significantly accelerate this process.

Real-World Case Studies: DNA in Action

Case Study 1: Atlantic Salmon - Winning the Fight Against Disease

Atlantic salmon farming is a major industry, especially in countries such as Norway, Chile, and Scotland. Farmers raise salmon in sea cages and depend on them for high profits. However, one major problem was frequent disease outbreaks, especially a viral disease called Infectious Pancreatic Necrosis (IPN).

Problems faced by farmers:

- ✓ Sudden death of a large number of fish
- ✓ Heavy financial losses
- ✓ High cost of medicines and management
- ✓ Uncertain production

Farmers noticed that some fish survived the disease, while some died quickly. This raised an important question: *“Why do some fish survive while others die?”* Scientists discovered that disease resistance in fish is largely controlled by genes present in their DNA. Some fish naturally possess strong immunity genes, which help them survive infections, while others have weaker genetic resistance and are more prone to disease. However, these genetic differences cannot be seen with the naked eye, making it difficult for farmers to identify strong fish based only on appearance. To solve this problem, scientists developed a method to identify superior fish using DNA markers. In this case study, the first step was to identify the most important trait, which was resistance to the Infectious Pancreatic Necrosis (IPN) virus (Figure 1). Scientists then studied a large number of fish and identified a specific region in the DNA, known as a Quantitative Trait Locus (QTL), that was strongly associated with disease resistance. This region contained a molecular marker, specifically a single-nucleotide polymorphism (SNP). Fish carrying this marker showed high survival against the disease, while those without it showed high mortality. Instead of waiting for disease outbreaks to identify resistant fish, scientists used a proactive approach. They collected a small tissue sample, such as a fin clip, from each fish, extracted the DNA, and tested it to check whether the resistance marker was present. This method is safe and does not significantly harm the fish. Based on these results, only fish that had the resistance marker, along with good growth performance and a healthy body, were selected as broodstock (parent fish). Fish lacking the marker were not used for breeding.

The selection process did not focus only on disease resistance. Multiple traits were considered to ensure overall performance. The most important trait was disease resistance, which determines the ability of fish to survive infections and is controlled by specific genes identified through molecular markers. Growth rate was another key trait, as fast-growing fish reach market size earlier, saving time and reducing costs. Feed efficiency was also considered, as fish that convert feed into body weight more effectively help reduce feed expenses, which is a major cost in aquaculture. Survival rate under farming conditions, including tolerance to stress, was another important factor. In addition, genetic quality was maintained by avoiding inbreeding and ensuring good genetic diversity in the population.

The results of this marker-assisted selection approach were highly positive. Disease resistance improved significantly, with fish carrying the marker showing much higher survival rates and greatly reduced mortality. Farm productivity increased because more fish survived until harvest, leading to lower economic losses. The need for medicines and chemicals decreased, reducing dependency on antibiotics and making farming more sustainable. Overall, farmers experienced better and more stable profits due to predictable production. In many cases, disease-related losses were reduced by as much as 50–70%, clearly demonstrating the effectiveness of this scientific breeding approach.

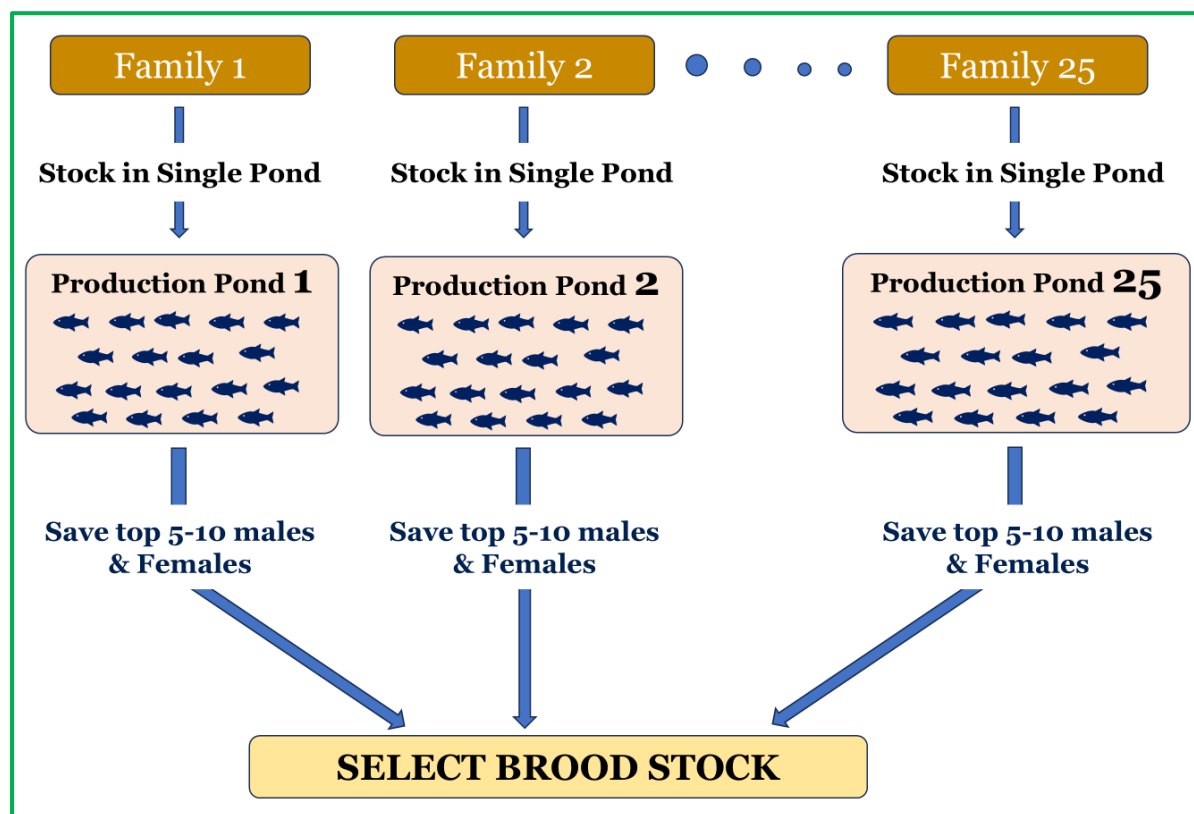


Figure 1: Selection Procedure for Atlantic Salmon

Case Study 2: Jayanti Rohu- A Success Story of Scientific Selective Breeding in India

Rohu is one of the most important freshwater fish cultured in India. To improve its production, scientists at ICAR-Central Institute of Freshwater Aquaculture developed an improved strain called “Jayanti Rohu” (Figure 2). This program is one of the best examples of selective breeding supported by molecular tools in Indian aquaculture. Earlier, farmers were using local Rohu seed, which showed poor and inconsistent performance.

Problems faced by farmers:

- ✓ Slow growth of fish
- ✓ Uneven size at harvest
- ✓ Low survival in some cases
- ✓ Poor quality seed from unorganised hatcheries

Farmers often noticed that even in the same pond, some fish grew fast while others remained small. This raised an important question: “Why do some Rohu grow faster and perform better than others?” To address this issue, scientists initiated a selective breeding program supported by molecular markers.

In this case study, the main traits identified were growth rate, survival, and overall performance. Scientists collected Rohu from different rivers across India to maintain wide genetic diversity. Using molecular markers such as microsatellites (SSR markers), they analysed genetic variation and ensured that selected broodstock were not closely related (to avoid inbreeding). Instead of selecting



Figure 2: Jayanti Rohu

fish only based on size, scientists combined family-based selection and genetic analysis. Fish families were reared separately, and their growth performance was recorded. At the same time, DNA analysis helped confirm genetic diversity and identify superior families. Based on both performance and genetic data, only the best-performing fish, those showing fast growth, good survival, and healthy body condition, were selected as broodstock. These selected fish were bred to produce the improved strain known as Jayanti Rohu.

Multiple traits were considered during selection. Growth rate was the primary trait, as faster-growing fish reach market size earlier and increase farmer profit. Survival rate was also important to ensure better production. Feed efficiency played a role in reducing input costs. In addition, maintaining genetic diversity was critical to avoid inbreeding depression and ensure long-term sustainability of the strain.

Table 1: Selective Breeding Case Studies in Aquaculture

Species	Programme / Location	Year Initiated	Traits Selected	Genetic Gain / Outcome	Key Findings	Reference
Atlantic salmon (<i>Salmo salar</i>)	Norway (AKVAFORSK programme)	1975	Growth rate, disease resistance (IPN), feed efficiency	~12–15% gain per generation; growth doubled in 5–6 generations	20% improvement in feed conversion ratio; mortality reduced in IPN-resistant lines	Gjedrem, T. (2000)
Rainbow trout (<i>Oncorhynchus mykiss</i>)	USA, Finland, Japan	1970s onward	Growth, disease resistance (IPN), spawning time	7–13% gain per generation	Disease-resistant strain showed only 4.3% mortality vs 96% in susceptible strain	Kause et. al., 2005 Dorson et. al., 1995
Coho salmon (<i>Oncorhynchus kisutch</i>)	USA (University of Washington)	1980s	Growth, survival, spawning time	~15% gain per generation; ~60% growth increase in 4 generations	Improved feed utilization and earlier spawning	Hershberger et. al., 1990
Nile tilapia (<i>Oreochromis niloticus</i>)	GIFT programme (WorldFish)	1988	Growth rate, survival	~17% gain per generation; growth nearly doubled in 5 generations	One of the most successful global breeding programmes	Eknath and Acosta, 1998
Rohu (<i>Labeo rohita</i>)	ICAR-CIFA, India (Jayanti Rohu)	1992	Growth rate, disease resistance	~17% gain per generation; growth doubled in ~3–4 generations	First genetically improved fish in India; resistant to <i>Aeromonas</i>	Mahapatra et. al., 2007
Catla (<i>Catla catla</i>)	ICAR-CIFA (Amrit Catla)	2010	Growth, feed efficiency, survival	~35% cumulative gain by 3rd generation	Improved productivity and disease resistance	Sahoo et. al., 2021
Common carp / Rohu carp	India (CIFA programme)	1990s	Growth rate	~29.6% gain per generation	Very high genetic variation; rapid improvement possible	Gjedrem et. al., 2012

Species	Programme / Location	Year Initiated	Traits Selected	Genetic Gain / Outcome	Key Findings	Reference
Giant freshwater prawn (<i>Macrobrachium rosenbergii</i>)	ICAR-CIFA + WorldFish (GI Scampi)	2007	Growth, disease resistance	~7.2% cumulative gain over 16 generations	Improved strain (CIFA-GI Scampi) developed	Pillai et. al., 2024
Shrimp (<i>Litopenaeus vannamei</i>)	Colombia (Ceniacua programme)	1990s–2000s	Growth, survival, WSSV resistance	4.2% (growth), 5.7% (survival), 1.7% (WSSV) per generation	Multi-trait selection improved overall performance despite trade-offs	Argue et. al., 2002 Cock et. al., 2009
Pacific oyster (<i>Crassostrea gigas</i>)	USA, Australia	1990s–2000s	Growth, survival	~9.5% gain per generation	Improved yield and weight significantly	Langdon et. al., 2003
Sydney rock oyster (<i>Saccostrea glomerata</i>)	Australia	2000s	Disease resistance	Mortality reduced from 85.7% to 63.5%	Strong improvement against parasite (<i>Marteilia</i>)	Nell and Perkins, 2006

The results of this breeding program were highly successful. Jayanti Rohu showed about 17–20% higher growth compared to normal Rohu strains. Farmers using this improved seed reported faster growth and earlier harvest, more uniform fish size, better survival rates, and higher overall production. This directly translated into increased income and reduced farming risk. Today, Jayanti Rohu is widely recognised as a successful example of how scientific breeding combined with molecular tools can improve aquaculture production in India. While the above case studies clearly demonstrate the practical application of selective breeding using molecular and conventional approaches, several other successful programmes listed in Table 1 further highlight the broad impact of genetic improvement in aquaculture. Species such as tilapia under the GIFT programme, catla, common carp, freshwater prawn, shrimp, and oysters have all shown significant improvements in growth rate, survival, feed efficiency, and disease resistance through systematic selection. In most cases, genetic gains ranging from 10–20% per generation have been achieved, leading to faster production cycles and increased farm profitability. Particularly in shellfish like shrimp and oysters, selective breeding has played a crucial role in enhancing resistance to major diseases and improving yield stability. These programmes collectively demonstrate that selective breeding, supported by molecular tools, is a reliable and sustainable strategy for improving aquaculture productivity across diverse species and farming systems.

Conclusion

Selective breeding supported by molecular markers has proven effective in improving growth, survival, and disease resistance in aquaculture species. Successful examples across fish and shellfish show consistent genetic gains and reduced farming risks. Adoption of improved strains can enhance productivity and profitability. This approach is essential for sustainable aquaculture and meeting future food demands.

References

1. Gjedrem, T. (2000). Genetic improvement of cold-water fish species. *Aquaculture Research*, 31, 25–33.
2. Gjedrem, T., & Baranski, M. (2009). *Selective Breeding in Aquaculture: An Introduction*. Springer.

3. Kause, A., Ritola, O., Paananen, T., Mäntysaari, E., & Eskelinen, U. (2005). Selection against early maturity in rainbow trout. *Aquaculture*, 247, 177–187.
4. Hershberger, W. K., Myers, J. M., Iwamoto, R. N., et al. (1990). Genetic changes in growth of coho salmon. *Aquaculture*, 85, 187–197.
5. WorldFish (2001). *GIFT Tilapia: Genetic Improvement Programme Final Report*.
6. Eknath, A. E., & Acosta, B. O. (1998). Genetic improvement of farmed tilapias (GIFT project). *Aquaculture*, 85, 187–197.
7. ICAR-Central Institute of Freshwater Aquaculture (CIFA Reports & Publications).
8. Mahapatra, K. D., Saha, J. N., et al. (2016). Jayanti rohu: A genetically improved strain of rohu. *Journal of Inland Fisheries Society of India*, 48(2), 1–8.
9. ICAR-Central Institute of Freshwater Aquaculture Technology Bulletin (Amrit Catla strain development).
10. Gjedrem, T., Robinson, N., & Rye, M. (2012). The importance of selective breeding in aquaculture. *Aquaculture*, 350–353, 117–129.
11. ICAR-Central Institute of Freshwater Aquaculture & WorldFish (2010). Genetic improvement of *Macrobrachium rosenbergii*.
12. New, M. B., Valenti, W. C., et al. (2010). *Freshwater Prawns: Biology and Farming*. Wiley-Blackwell.
13. Argue, B. J., Arce, S. M., Lotz, J. M., & Moss, S. M. (2002). Selective breeding of Pacific white shrimp for growth and disease resistance. *Aquaculture*, 204, 447–460.
14. Cock, J., Gitterle, T., et al. (2009). Breeding for disease resistance of penaeid shrimps. *Aquaculture*, 286, 1–11.
15. Gitterle, T., Salte, R., et al. (2005). Genetic (co)variation in shrimp breeding programmes. *Aquaculture*, 246, 139–148.
16. Langdon, C., Evans, F., et al. (2003). Selective breeding of Pacific oysters. *Aquaculture*, 220, 253–267.
17. Nell, J. A., & Perkins, B. (2006). Selective breeding for disease resistance in Sydney rock oyster. *Aquaculture Research*, 37, 1444–1451.