RESEARCH PROGRAM ON Fish

CGIAR

Led by WorldFish

# Fish breeding and genetics for improved productivity, profitability and sustainability of small-scale farms

Photo credit: Md Masudur Rahaman/WorldFish

The lack of access to improved strains[1] for many farmed fish species is a major impediment to achieving efficient and sustainable fish farming across the globe.[2] The success of genetic improvement in salmon and shrimp has shown the immense potential of selective breeding for aquaculture. Access to genetically improved fish strains for locally important species in Africa and Asia is critical to achieving food and nutrition security and sustainable livelihoods for millions of people. Key species include Nile tilapia and rohu, catla and silver carps, which collectively provide 27 percent of the world's farmed finfish production.[3]

Fish that grow faster and survive well reduce risks that threaten food and nutrition security and increase the likelihood of providing sufficient yields for sustainable livelihoods. However, under a changing climate, the development of more resilient fish is required. The CGIAR Research Program on Fish Agri-Food Systems (FISH) aimed to respond to demand from small- and medium-scale farmers for fish strains with superior performance in the diverse aquaculture systems across Africa and Asia. To address this, key objectives included

1. development and dissemination of faster growing tilapia and carp strains;
2. identification and characterization of new productivity and resilience traits to incorporate in fish genetic improvement programs;
3. development of genomic tools, methods and knowledge to accelerate genetic gain and incorporation of new traits in fish breeding programs;
4. understanding the trait preferences of poor men and women for genetically improved fish.

**Key messages**

- Faster growing tilapia strains demonstrate continued increase in growth rate in genetic improvement programs and superior profitability for farmers in Africa and South Asia, with reduced environmental impact.
- New genetic improvement programs for three carp species (rohu, catla, silver carp) in Bangladesh have begun, with the release of a rohu strain with 30 percent faster growth to farmers scheduled for 2022.
- New traits characterized in tilapia promise better performance and adaptation to climate change through tolerance to low dissolved oxygen conditions, resistance to tilapia lake virus (TiLV), and improved feed efficiency.
- New molecular genetic tools (SNP array, reference genomes, linkage maps, genetic markers for host disease resistance) will underpin genomic selection, accelerate development of resilient fish strains and promote sustainable management of aquatic genetic resources.
- The preferences of poor women and men farmers for traits to be improved in farmed fish show some differences between genders and geographies, but highlight the importance of fast growth and large fish for both genders.
- Enabling policy, investment and capacity development are necessary for these promising genetic findings and innovations to deliver their full impact.

## Research findings and innovations

### Faster growing tilapia and carp strains improve profitability for farmers and reduce environmental impact

Over the past two decades, WorldFish and partners have developed and disseminated improved tilapia strains with faster growth and high survival rates, notably Genetically Improved Farmed Tilapia (GIFT) in Southeast Asia and Bangladesh and the Abbassa strain in Egypt. Wide dissemination has provided positive impact in low- and middle-income countries and proved the utility of GIFT strains.[4]

FISH research has continued the carefully designed and managed genetic improvement programs in tilapia, which are based on selective breeding, maintaining gains in growth rate over several generations of 7 percent per generation in GIFT and 3 percent per generation in the Abbassa strain.[5] Dissemination of recent generations has shown greater profitability for farmers, including poorer farmers, using GIFT in Bangladesh and the Abbassa strain in Egypt compared to culture of other strains. Both improved strains also have better feed conversion ratios and so are able to more efficiently use resources, resulting in a lower environmental footprint.

The response to selection for growth rate in fish is greater than for most terrestrial livestock. Additionally, the many offspring produced by fish (500–1000 for tilapia, two for cattle) mean the improved material can be multiplied quickly for dissemination to farmers through regional networks.

Photo credit: Silvino Gomes/WorldFish

FISH has focused on scaling the benefits of faster growth in tilapia to other key fish species for small-scale farmers and consumers. New genetic improvement programs for rohu (three generations), catla (one generation) and silver carps (one generation) have been established in Bangladesh. These are key species farmed in the highly productive polyculture systems of Bangladesh, making up 60 percent of carp production, and generally preferred by consumers (rohu, catla), including poorer consumers (silver carp). FISH researchers and partners achieved improvements in growth rate for rohu and silver carp of around 10 percent per generation, with preliminary data for catla expected in 2022. The third generation of rohu is being tested on farms and is expected to yield at least 30 percent larger fish than existing strains, with plans for release to farmers in 2022. Given carps produce up to a million eggs each, the potential for rapid dissemination, and therefore impact, of the improved strain is considerable.

Faster growth rate was prioritized in fish genetic improvement programs because of the rapid response to selection and the associated positive impact for farmers of improved yields and profitability. However, environmental changes exacerbated by climate change will require fish that are resilient in the face of environmental stress.

## New fish resilience traits to help farmers adapt to climate change and emerging disease

An expert team from WorldFish, Wageningen University Animal Breeding, The Roslin Institute, Earlham Institute and the French Agricultural Research Centre for International Development was developed to explore key characteristics for resilient fish under climate change, including tolerance to low or variable oxygen levels, which are exacerbated by higher temperatures, and host resistance to fish diseases, which are predicted to increase with climate change.[6] The critical first step for developing more resilient farmed fish lies in understanding whether a fish species has these capabilities and the extent to which they will respond to genetic improvement.

The FISH team investigated three key characteristics in GIFT related to tolerance of low dissolved oxygen conditions, disease resistance (focused on TiLV) and the efficiency of feed use. All were shown to be heritable and thus possible to improve using selective breeding with the aid of new advanced genetic techniques.

Tolerance to low dissolved oxygen conditions is important in Africa and Asia. Most causes of yield gaps can be addressed by better management, such as pond preparation and feeding regimes, but in areas without power, oxygen cannot be supplied by aeration, thereby limiting production. Experiments comparing fish growth in aerated and non-aerated ponds and fish tested for exercise efficiency (a measure of oxygen tolerance) demonstrated heritable variation for these traits in GIFT. These findings provided a realistic prospect of developing improved strains selected for growth in low oxygen environments.

The introduction and spread of infectious fish diseases is already one of the main limitations to aquaculture productivity,[7] and diseases are projected to become more frequent as environmental stressors increase with climate change.[6] For example, TiLV is an important emerging disease threatening the livelihoods, food and nutrition security of millions of small-scale tilapia farmers. Investigation of a TiLV outbreak in different families of GIFT provided evidence of high heritability, and therefore the ability to develop resistant fish strains. The use of genetic markers to identify fish resistant to TiLV will allow faster development of a resistant strain.

Fish feed can account for up to 70 percent of production costs.[8] As such, efficiency of feed use is immediately important for farm profit and also reduces the relative environmental footprint of feed production, pollution and waste. FISH research shows greater efficiency, thought to arise from selection for faster growth, of GIFT in Bangladesh and Ghana, the Abbassa strain in Egypt and other faster growing strains in Kenya. An important finding from a challenging set of experiments with tilapia over 3 years suggests that it is possible to select specifically for feed efficiency separate from growth, providing a new avenue to obtain more sustainable fish production.

These traits cannot be simply observed in living fish or easily measured, as size and growth can, so research on the relationship of each trait to molecular DNA markers was undertaken.

## Genomic knowledge to accelerate genetic gain and delivery of resilient fish to farmers

Genomic tools can add considerable value to selective breeding, and particularly, to develop fish of superior performance with crucially important climate and disease resilience traits. A basic requirement is the ability to identify variation in many sites of the DNA from many individuals. This is achieved most simply through next generation sequencing or a SNP (single nucleotide polymorphism)[9] array using small samples of fin tissue. FISH researchers developed essential tools, including a SNP array, genetic maps and reference genome assemblies for tilapia strains. The tools

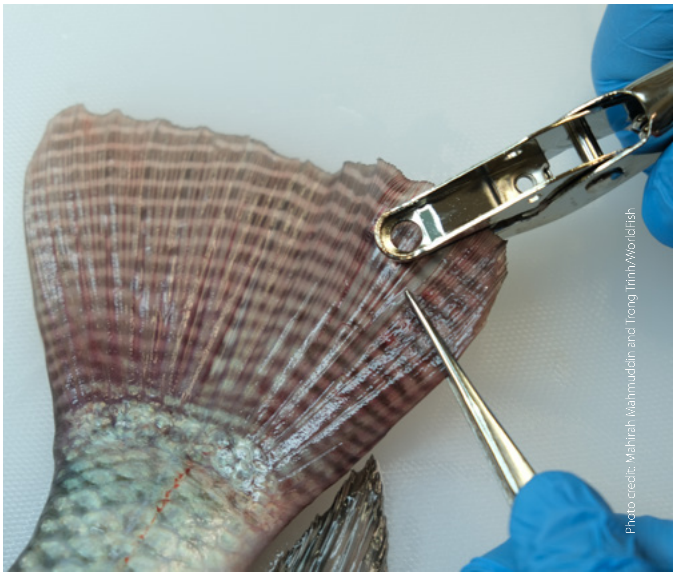
Photo credit: Mahirah Mahmuddin and Trong Trinh/WorldFish

were applied to solve key practical issues in selective breeding programs for GIFT and the Abbassa strain and to assist regional assessments of aquatic genetic resources in Africa and Asia.

Next generation sequencing was used to assay 9000–12,000 SNPs each in rohu, catla and silver carps. Every parent was assayed for all SNPs for the species, which allowed their genetic relationships to be calculated to avoid the mating of close relatives (e.g. brother and sister, parent and offspring). The method provided a cheap, powerful and rapid way to minimize inbreeding in captive breeding programs. Similarly, in partnership with James Cook University, screening several thousand SNPs for the Abbassa strain highlighted issues in the historical accuracy of pair mating, together with evidence of hybridization with the cold-tolerant blue tilapia species. This provided an explanation of the slower response to selection to date relative to GIFT and a new pedigree was created, permitting faster improvement in the future.

SNP arrays provide rapid and repeatable assay of the same set of SNPs in many individuals. A low-density SNP array (1000 SNPs) was developed to distinguish domesticated tilapia strains in Asia to help understand their use in farming systems and improve traceability in tilapia seed systems. Surveys using the SNP array in Bangladesh showed, for example, that many hatcheries did not hold the stocks they thought they did, and that 50 percent of tilapia stocks were derived from GIFT. FISH and partners also developed the first open access Nile tilapia SNP array, which was primarily based on GIFT and Abbassa strain DNA (60,000+ SNPs). This powerful tool enables genomic selection in Nile tilapia and the assessment of wild genetic resources. The SNP array has been used to assess parental relationships in the genetic improvement programs of the Abbassa strain and the indigenous three-spotted tilapia in Zambia,[10] and is readily obtainable from ThermoFisher.[11]

This SNP array was used to assess the genetic architecture of host resistance to TiLV via a genome-wide association study. WorldFish and The Roslin Institute detected a major quantitative trait locus on tilapia chromosome 22 and several specific SNPs which can be used in marker-assisted selection to improve genetic resistance.

WorldFish and the Earlham Institute joined forces to provide the first highly accurate and detailed genomes for GIFT and Abbassa tilapia strains. These will guide breeding decisions and help more accurately identify the position of trait-associated genetic markers, such as those mentioned for TiLV identified in partnership with The Roslin Institute, and for faster genetic selection of resilience traits.

The research on genetic tools has resulted in a powerful platform of technologies that can be used in various ways, including for further development of resilient tilapia and carp and management of genetic diversity (e.g. preventing deterioration of seed systems, characterizing wild fish biodiversity).

## Understanding trait preferences of poor men and women to ensure relevance of genetic improvement programs

Genetic improvement programs require a clear understanding of the needs of users in order to develop helpful products. These needs vary among users with different roles along fish value chains and for different sectors of the market. In the first gender disaggregated study of fish trait preferences for genetic improvement, surveys of producers and consumers in Bangladesh and India showed similar high preference by men and women for faster growing or larger rohu carp, confirming the suitability of the main targets for current genetic improvement programs. However, there were some strong gendered differences, relating to fish shape and color that need further investigation. There were also geographic differences, as men and women prioritized faster growth in Bangladesh and larger size fish in India. In both cases these preferences would be met by genetic selection for faster growth, which can lead to large fish. The surveys also demonstrated challenges of developing joint understanding of simple characteristics identified by a farmer, like fish that grow well and survive, to more specific biological traits that would be selected in genetic improvement programs, including weight at a given age or resistance to a particular disease.

## Scaling FISH research

FISH has extended previous genetics research to create a strong platform for developing more resilient fish over the next decade. This establishes a broader foundation of genetic gain in fish upon which improvements in fish feeds, health and farm management can build more secure and sustainable livelihoods for farmers.

## Policy and investment recommendations

FISH and partners have provided support for developing international mechanisms to implement access and benefit sharing and other aspects of aquatic genetic resource management, including a global information system and plan of action, through engagement with the UN's Food and Agriculture Organization and regional intergovernmental bodies, including the Southern African Development Community and East African Community. However, realizing the benefits of these advances require

- developing sustainable commercial suppliers that operate at sufficient scale, with clear mechanisms to link to small-scale farmers, essential for enabling delivery of FISH research;
- investment in capacity building and support, including regional or national continuation of FISH efforts to train postgraduate students, mentor genetic improvement programs in India, Ghana, Egypt, Malawi, Mozambique and Zambia, and provide technical assistance to multiplication centers in Myanmar and Timor-Leste;
- improved policy and implementation of access and benefit sharing, benchmarking and market assessments, and biosecurity measures for more effective sustainable management and development of aquatic genetic resources;
- regional developments with clear and practical mechanisms to deal with access and benefit sharing and cross-border arrangements.

## Areas for future research

Further research is needed to incorporate new traits in fish strains as part of efforts to improve aquaculture systems to meet the needs of diverse end users. Continued work with fish feeds and disease experts is also needed to address yield gaps identified in practical use. Priorities include the following:

- rapid and efficient measurement of new traits and further information on the relationships among traits to aid their incorporation into new fish strains
- discovery of functional genes and variants underpinning quantitative trait loci associated with key production traits, such as disease resistance, to facilitate development of new genomic tools and methods that improve selection accuracy and genetic gain in breeding programs
- development of refined surveys and survey strategies to develop mutual understanding of user trait preferences where perceptions differ and decision support tools to prioritize diverse preferences
- benchmarking information on the performance of fish strains in different aquaculture systems to inform changes in farming practices or modifications in the genetic improvement program.

## Notes

[1] "Strain" is used for consistency with program documentation, but the authors recognize "farmed type" as the new formal terminology for all genetic resources of farmed organisms below the species level. See the FAO Aquaculture Newsletter (April 2020, No. 61) for further discussion.

[2] FAO. 2019. The State of the World's Aquatic Genetic Resources for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture assessments. Rome: FAO. https://www.fao.org/aquatic-genetic-resources/activities/sow/en/

[3] FAO. 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome: FAO. doi: 10.4060/ca9229en

[4] Spielman DJ and Pandya-Lorch R. 2009. Millions fed: Proven successes in agricultural development. Washington, DC: International Food Policy Research Institute.

[5] See the following for further discussion about growth rate gains in the Abbassa strain: Nayfa MG, Jones DB, Lind CE, Benzie JAH, Jerry DR and Zenger KR. 2020. Pipette and paper: Combining molecular and genealogical methods to assess a Nile tilapia (Oreochromis niloticus) breeding program. *Aquaculture* 523. doi: 10.1016/j.aquaculture.2020.735171

[6] Alders RG, Chadag MV, Debnath NC, Howden M, Meza F, Schipp MA, Swai ES and Wingett K. 2021. Planetary boundaries and Veterinary Services. *Revue Scientifique et Technique* Off Int Epiz. 40(2):439–53. English. doi: 10.20506/rst.40.2.3236

[7] Subasinghe RP, Delamare-Deboutteville J, Mohan CV and Phillips MJ. 2019. Vulnerabilities in aquatic animal production. *Revue Scientifique et Technique* 38(2):423–36. English, French, Spanish. doi: 10.20506/rst.38.2.2996

[8] Boyd CE, D'Abramo LR, Glencross BD, Huyben DC, Juarez LM, Lockwood GS, McNevin AA, Tacon AGJ, Teletchea F, Tomasso JR Jr et al. 2020. Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. *Journal of the World Aquaculture Society* 51:578–633. doi: 10.1111/jwas.12714

[9] Single nucleotide polymorphisms are variations in single bases, the smallest units of DNA, which provide useful genetic markers between individual organisms.

[10] Basiita RK, Kakwasha K, Chungu P, Malambo T, Trinh TQ and Benzie JAH. 2020. Report on species mapping, purity in hatcheries and review of best management practices. WorldFish. Technical Report 02. Prepared for the Ministry of Fisheries and Livestock, Department of Fisheries. https://hdl.handle.net/20.500.12348/4623

[11] The tilapia SNP array is available for commercial purchase from ThermoFisher (array number 551071, E-mail: BioinformaticsServices@thermofisher.com).

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This is a contribution to the following:

1 NO POVERTY | 5 GENDER EQUALITY | 13 CLIMATE ACTION | 14 LIFE BELOW WATER

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