Approaches to National Fish Breeding Programs: Pointers from a Tilapia Pilot Study

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Tilapias are widely recognized as one of the most important species for farming in a wide range of aquaculture systems from simple small-scale waste-fed fishponds to intensive culture systems. Annual production exceeds 50,000 tonnes in several Asian countries. There is significant tilapia culture in Bangladesh, China, Indonesia, the Philippines, Sri Lanka, Thailand and Vietnam. Interest in tilapia culture is also increasing elsewhere in the Indian subcontinent and the Pacific-rim countries including the USA, and Africa. Tilapia has been dubbed the "aquatic chicken".

Genetic research and breeding programs have been major contributors to the significant production improvements in terrestrial agriculture (see box 1). These achievements have resulted from combined improved knowledge in nutrition, farming systems, health care, animal breeding and others. At least 30% of total gains in the rate and efficiency of production can be attributed to genetic improvement. The estimated benefit to cost ratios of such genetic improvement programs range from 5:1 to 50:1.

Aquaculture has so far remained almost untouched by the advances in applied breeding technology even though the tradition of fish farming dates back thousands of years. There are several reasons for this. Aquaculture research in general and genetic improvement research in particular have been hampered by short-term, scattered and disjointed funding. Long-term strategic research efforts have been neglected.

The few studies on genetic improvement of aquatic species have demonstrated that the potential for achieving rapid genetic gains is in general very high. This is due particularly to the large genetic variability in most economically important traits, high fecundity of most fish and the ease with which prime aquaculture species can be bred in captivity. The "supertrout" developed by Dr. L. R. Donaldson of the University of Washington, the Hungarian 'land races' of carps and Norwegian salmon and trout are notable examples.

A Framework for Developing Breeding Programs

An applied fish breeding program may be organized on different levels from the simplest individual selection programs to the more advanced combined selection programs, with or without initial testing to evaluate genetic parameters.

So far there is no sustained applied breeding program anywhere in the tropical developing world and therefore no mechanism for learning by experience how to develop such programs to suit the needs of existing and new entrant fish farmers. The Genetic Improvement of Farmed Tilapias (GIFT) project is a pioneering effort in this direction – several decades behind animal and plant breeders (see p. 3). The focus is on Nile tilapia (*Oreochromis niloticus*), a species with great immediate potential. Because of the pioneering role of the GIFT project, an elaborate design was chosen to seek answers to a broad range of basic problems in fish breeding programs.

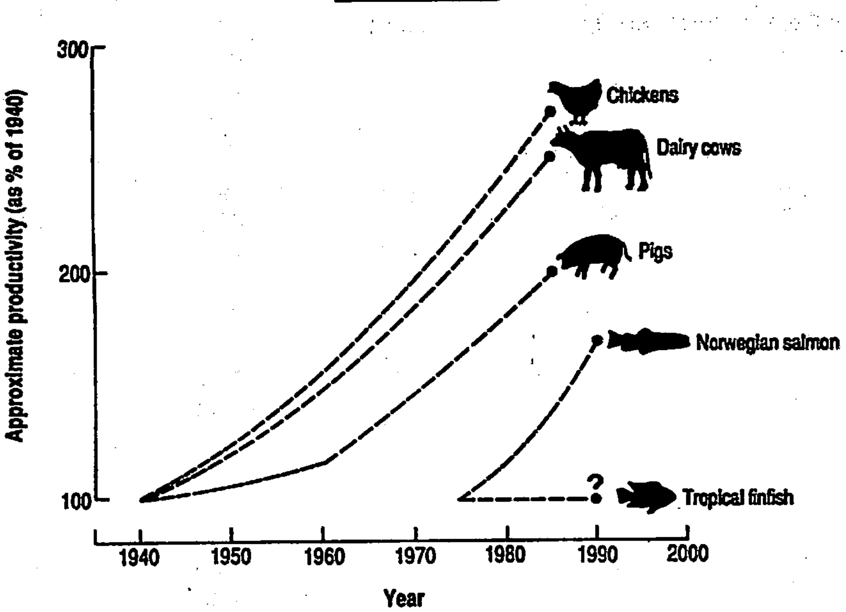
The important sequential steps in developing a practical breeding program are described below. We use the GIFT project experience as an example of each step.

1. Analysis of targeted production and marketing systems

Quantitative information should be collected and analyzed on farm environments; management levels; agroclimatic conditions; duration of production cycle; inputs (feeds, labor, fertilizers, etc.), ages and weights at breeding and marketing, and all other relevant stages in the production cycle. It is important to be prepared from the beginning for any technological advances and make provisions for them in the breeding program. The flow of genetic material between the various segments of the culture industry, from hatcheries to growout should be considered.

At the very outset, the GIFT project considered the relative economic importance of each of different diverse tilapia farming systems including simple backyard fishponds, rice-fish culture, cage culture and relatively intensive systems. A growout period of 90 days (from fingerling stage) was chosen as a representative production cycle. The industry as such is relatively well organized into hatcheries and growout, offering a

BOX 1



Genetic research initiated in the 1940s has resulted in remarkable developments in increasing the productivity of domestic mammals and birds. The average number of eggs laid per year by a hen steadily increased from approximately 120 in the 1940s to more than 320 by the mid-1980s; the average milk production per cow in a single lactation of 305 days increased from approximately 2,000 kg in 1945 to more than 5,000 kg by 1980. Average daily gain in the pig industry has increased from about 450 g by the start of the modern breeding programs around 1960 to about 800 g in the 1980s. After 15 years of accumulated selection and improved feeding and management, productivity in the Norwegian salmon industry has increased by 60-70%.

Aside from increased yields, these programs have greatly improved feed efficiency and reduced the duration of the production cycle. The time to produce a 1.7 kg broiler has been reduced from 14 weeks to 7 weeks and the amount of feed required has been reduced by one-half. The number of dairy cows required to produce the same amount of milk as in 1945 has been reduced from 26.6 million to 11.6 million.

Productivity of most farmed finfish species in the tropics has remained almost constant, close to that of the wild stocks.

good setting for rapid dissemination of genetic gains.

2. *Breeding goals*

From analysis of the production system, it should be possible to identify and prioritize the various segments of the production cycle which need improvement. The criteria are relative economic importance of traits and benefit to cost ratios. Breeding in general is a long process. Goals should be pertinent over many generations.

Immediate breeding goals generally focus on increasing the production efficiency, through better growth and efficiency of food utilization. In the case of tilapias, which reach maturity before they reach harvest size, immediate breeding goals should also include selecting for late maturity.

Long-term breeding goals generally involve the whole industry, encompassing an array of traits of economic importance, such as survival, resistance to diseases and stress, product quality, etc., which eventually lead to domestication of the stocks and establishment of a viable industry.

3. *Systematic documentation and evaluation of available genetic resources and choice of genetic base*

Genetic improvement programs should start with the best available resources, otherwise one can spend years developing the "best" strains from relatively inferior stocks. The cost of lost opportunities can be considerable. The founder population must have a broad genetic base. It is worthwhile sifting through the literature to collate all available information on both wild and established farm stocks. Individuals from a large number of populations can then be combined to form a "synthetic" population to secure genetic variability.

The necessary background work for the GIFT project was initiated during a special Workshop on Tilapia Genetic Resources for Aquaculture in 1987 (see p. 3) which concluded that the established farm stocks in Asia do not form the best genetic base for a genetic improvement program because of small founder populations originally imported, possible inbreeding and widespread introgression of genes from other less desirable feral tilapia species. Based on the recommendations of the workshop, the GIFT project brought diverse tilapia germplasm from Africa. The strategy was to evaluate the new germplasm along with the established farmed stocks in different Philippine tilapia farming systems to build a base (synthetic) population by selecting the best individuals across populations.

4. *Number of strains*

The most important criterion determining the number of strains to be developed is their relative performance in different target environments. In genetic parlance, this is called genotype-environment (GE) interaction. If there is no GE, then the best strains in one environment will be the best in all. On the other hand, if there is high GE then special strains must be developed for specific environments.

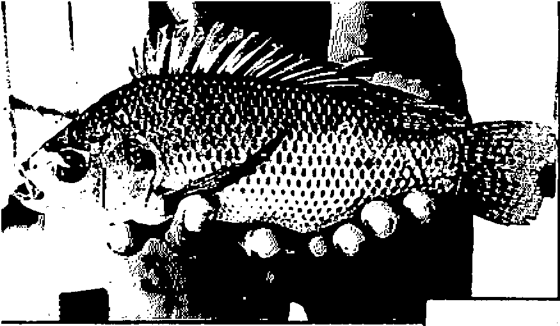
In determining the target environments, emphasis should be on the relative importance and proportion of commercial production represented by each of the environments (see 1 above), and whether or not existing environments will prevail in the foreseeable future.

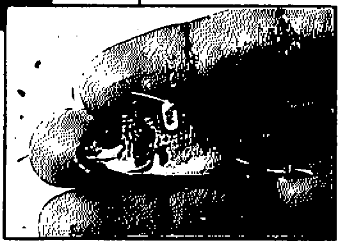
The GIFT project found that there was low GE in the growth performance of four new African strains and four established Philippine farmed stocks in a wide range of farming systems and agroclimatic conditions. Thus, the best performing strains could be mixed together to build one base population. However, the GIFT plan is to test breeding material across all target environments during every cycle of selection to ensure that the response to selection will be valid outside the environments in the breeding nucleus.

5. *Breeding strategy*

The major alternative breeding systems are purebreeding and crossbreeding.

Purebreeding as a breeding strategy focuses on additive genetic variance – choosing the best performing individuals as breeders in every generation. The genetic





Tagging of fish is essential to include pedigree information and increase accuracy of selection through combined selection strategies. The period of separate rearing of families before tagging should be minimized to avoid large common environmental effects. In the GIFT project, procedures for tagging fish as small as 3 g have been standardized.

changes brought about by purebreeding are cumulative and permanent. Purebreeding programs hinge around three genetic parameters: heritability, genetic variation and genetic correlations between traits. Depending on heritability for a given trait, different types of purebreeding strategies can be adopted: mass selection, within-family selection, family selection, progeny testing and a combination of one or more types. Purebreeding programs are resource efficient, simpler in design and easier to implement than crossbreeding programs, and the genetic gain is sustainable during generations of reproduction outside the breeding system.

The potential products of crossbreeding include heterosis (hybrid vigor), introgression of genes (desirable traits) into candidate species, establishment of base populations for selection, combination of specific traits, and production of monosex and sterile hybrids. As a breeding strategy, crossbreeding focuses on nonadditive genetic variance (heterosis). Expected heterosis levels should be substantial to adopt crossbreeding. To use crossbreeding only, however, is a static procedure. It should be combined with some form of selection, either selection within each line used to produce the crossbreds, as in many poultry programs or, for example, by reciprocal recurrent selection procedures.

An important problem with crossbreeding is to find ways of predicting performance of crossbreds. Substantial resources are needed to compare merits of all possible crosses (for example, for only four lines there are 12 possible two-line, 96 three-line and 132 four-line crosses). It also requires very careful attention to pedigrees, otherwise the whole program will degenerate.

Other forms of genetic manipulation aimed at maximizing productivity of stocks, including ploidy manipulation, sex manipulation, and introduction of exotic genes through backcross and emergent biotechnology techniques, should also be considered (see article by Pandian and Varadaraj in *Naga*, July 1990, p. 3). Integration of approaches wherever possible will benefit the industry.

In tilapias, several studies have demonstrated low levels of heterosis. The mean level for growth and survival in the GIFT project is 2.3%. A selection program commencing with a broad genetic base population (see step 4) of best performing individuals, irrespective of their origin, was therefore chosen for genetic improvement of Nile tilapia.

6. Selection criteria and evaluation

This step involves accurate recording of traits at predetermined stages of the production cycle (step 2) to maximize response to selection. Tagging of individuals is essential for all purebreeding strategies except simple mass selection. However, in mass selection with mixed age groups, tagging is essential. A nested or hierarchical mating system (one male mated to several females or vice versa) should be used for a pedigreed stock.

Following the establishment of the base population, the GIFT project is at present carrying out the first generation of selection. The primary objective is to select for growth rate. Other traits such as age at first spawning and survival are also being recorded for possible inclusion during the later generations of selection.

7. Production and dissemination of improved strains

These should be concurrent with the breeding program. Effective dissemination of genetic gain is possible only when there are organized channels for production and distribution of fish seed to farmers (step 1). Farmer participation is crucial.

The GIFT project anticipates dissemination of improved breeds within the Philippines in 1992. Initially, it will be done through the existing national broodstock center (breeding nucleus) and nationwide satellite stations (multipliers). The project envisages a farmer-owned breeding program after a few years.

8. Social, economic and environmental impacts

The development objective of national breeding programs is to increase the quantity and quality of fish protein.

In broad economic terms, the GIFT project expects that soon its improved tilapia strains will grow at least 20% faster, partly due to the introduction of new germplasm from superior strains and partly due to response to selection. In some circumstances this will allow three instead of two crops per year; in others, production of 20% larger fish per crop. These profitability increases at the farm level will create the incentive for wider adoption of tilapia farming.

Protocols for assessing environment impacts are being formulated in consultation with experts in this field.

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