SELECTIVE BREEDING OF NILE TILAPIA FOR ASIA*

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SUMMARY

The focus of this paper is on the results of a multidisciplinary research and development program implemented by ICLARM and its partners since 1988 under the auspices of two projects: the "Genetic Improvement of Farmed Tilapia" (GIFT) and the "Dissemination and Evaluation of Genetically Improved Tilapia in Asia" (DEGITA). The program has two themes: (a) evaluation of Nile tilapia genetic resources and their utilization in national breeding programs; and (b) monitoring of the adoption of improved Nile tilapia breeds with regard to their impact on equity, the environment and biodiversity.

Selective breeding of Nile tilapia has involved: (a) assembling of tilapia germplasm from their wild habitats in Africa and from "domesticated" Asian aquaculture stocks; (b) estimation of genotype x environment interaction in diverse Asian farming systems; (c) a complete diallel crossing experiment to determine the magnitude of heterosis; (d) establishment of a base population and initiation of selection to improve growth performance. The genetic gain per generation across five generations of selection has been about 12-17 %. Production trials and socioeconomic surveys in five Asian countries reveal that the cost of production per unit of fish produced is 20-30% lower for the GIFT strain than for other Nile strains in current use. Price elasticity data indicate that yield increases by using GIFT strain would benefit mostly the vast group of poor consumers.

There is growing need for genetic research on different tropical fish species to close the looming gap between demand for and supply of food fish. An International Network on Genetics in Aquaculture was established in 1993 with 13 Asian and African countries to include research on other species, especially the carps.
Keywords: Nile tilapia (*Oreochromis niloticus*), selective breeding, GIFT program.

INTRODUCTION

Fish Breeding - a nascent scientific discipline. Most of the aquaculture stocks in current use are generally similar to wild undomesticated stocks and in some situations there is evidence for

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genetic deterioration (Eknath *et al.* 1991). It has been widely assumed that genetic intervention will require extensive resources and, therefore, should be considered as an option for the future. Research activities so far have focused on optimizing routine pond management practices. Genetic research, if at all, has been sporadic, short-term and scattered.

Simple genetic improvement can easily be applied to tropical aquaculture (for example, Doyle 1983; Gall 1983; Gjedrem 1983; Eknath and Doyle 1985, 1990; Bentsen 1990). The selective breeding program for Nile tilapia (*Oreochromis niloticus*) in Asia has followed the pioneering Norwegian example of AKVAFORSK (Gjedrem 1985, 1992) but had to consider the complexities unique to aquaculture in a developing country context and also the social lessons learned from the green revolution in crop production. It is the first major multidisciplinary research, training and development initiative in the tropical developing world with two themes: (a) documentation, evaluation, and utilization of Nile tilapia genetic resources in national breeding programs for the benefit of small scale tilapia farmers; and (b) monitoring of the adoption of improved Nile tilapia breeds with *ex ante* estimation of impacts on equity, environment and biodiversity. These goals are comprised by two projects: the "Genetic Improvement of Farmed Tilapias" (GIFT) project implemented by ICLARM in cooperation with BFAR/NFFTRC, FAC/CLSU and AKVAFORSK; and the "Dissemination and Evaluation of Genetically Improved Tilapia in Asia" (DEGITA) project implemented by ICLARM in cooperation with national institutions in Bangladesh, Peoples Republic of China, Philippines, Thailand and Vietnam. Nile tilapia was chosen as a model species because of their growing importance in tropical and subtropical aquaculture, their short generation interval of about 6 - 8 months, and their utility in investigating the application of genetics in aquaculture.

Role of tilapias in Aquaculture. Tilapias, dubbed the 'aquatic chicken' (Maclean, 1984), are freshwater fish indigenous to Africa. They have been the main stay of small-scale aquaculture for many farmers in the developing world. The 'backyard' type tilapia farming coexists with sophisticated medium and large-scale corporate farms. FAO statistics report tilapia culture in at least 75 countries and world production of tilapia in 1994 was about 600,000 mt with an estimated value of about 835 million US dollars (FAO 1996). The most widely preferred species is the Nile tilapia, which contributes about 55% to the global production.

Production in Asia has increased from about 155,000 mt in 1984 to 520,000 mt in 1994. Asia accounted for 87% of the global tilapia production during 1993 and 1994. Peoples Republic of China, the Philippines, Indonesia, Thailand and Taiwan, respectively, contributed 43, 19, 12, 11, and 10% of the total production. Dey and Eknath (1997) and Pullin (1996), respectively, describe the Asian tilapia industry profile and the perceived constraints to expansion of tilapia aquaculture.

SELECTIVE BREEDING OF NILE TILAPIA

Guiding Principles. Aquaculture in general, tilapia farming in particular, represents a new dimension in fish farming not only to the existing farmers but also to many new entrants. Majority of the fish farmers are small scale operators (less than 1 ha) practicing extremely diverse systems. The institutional infrastructure to develop and disseminate the results of fish genetic improvement programs are inadequate. Therefore genetic improvement strategies destined to benefit the fledgling aquaculture industry should presume minor or gradual structural changes.

The program has involved consultations with fish farmers and experts from various disciplines. The relative economic importance was considered of each of the diverse tilapia farming systems including the backyard fishpond, rice-fish culture, cage culture and some more intensive systems. A grow-out period of about 90 days (from the fingerling stage when the fish are about 3-7g to their harvest weight of about 120 g) was chosen as a representative production cycle. Standardized research methods were then developed for mating, mass marking of individual fish, sampling, anesthesia, recording of traits and pedigree, management of databases, statistical analyses, and quarantine and safe dispersal of fish (Acosta and Eknath, 1997).

The Process. *Assembling Nile tilapia germplasm.* While the global wealth of tilapia genetic resources are restricted to Africa and the Levant, the main aquaculture industries are at present in Asia. The established farm stocks in Asia derive from very small founder stocks, and possibly suffer from inbreeding and widespread introgression of genes from other less desirable feral tilapia species (Pullin 1988; Dey and Eknath 1997). The GIFT Project partners collected wild Nile tilapia germplasm from Egypt, Ghana, Senegal and Kenya (Pullin 1988; Eknath *et al.* 1993). Philippine commercial Nile tilapia strains were also gathered, giving a total of eight strains for study. These have been described using biochemical markers (Macaranas et al. 1995) and truss morphometrics (Velasco et al. 1996). Spermatozoa from founder stocks and from subsequent generations are being cryopreserved.

Genotype x Environment interaction (GE): The GIFT project's first major experiment was to determine the growth performance of strains and the magnitude of GE over two consecutive generations (Eknath et al. 1993). The 11 test environments chosen covered a wide range of tilapia farming systems: earthen ponds fertilized with organic manure, ponds fertilized with on-farm agricultural residues, rice-fish systems, cages, and hatcheries located in different agro-climatic regions. A total of 11,000 individuals (7650 and 3420 individuals during first and second generation) were communally reared in all test environments for 90 days. Results indicated highly significant differences in growth performance among the strains. Excepting Ghana strain, the wild African strains performed as well as or better than the 'domesticated' strains used by the Philippine farmers. The widely cultured Israel strain in the Philippines performed poorly (Fig. 1). The GE was low. Overall, the growth performance of the strains were relatively consistent across test environments. It was concluded that development of specialized strains for each of the farming systems in the Philippines may not be necessary. However, the GIFT plan incorporates testing of breeding materials across all target environments to ensure that the response to selection will be valid in almost all grow-out environments.

Breeding strategy. The GE experiment was followed by a complete diallel crossing experiment producing all 64 hybrid and pure strain combinations among the eight founding strains to estimate the magnitude of heterosis (Bentsen *et al.* in press) Growth performance was recorded in a total of 23,739 individually tagged progeny after a grow-out period of about 90 days. Least square means (LSM) of body weights at harvest were computed for each strain combination within and across all test environments, and additive genetic effects, maternal (reciprocal) effects, and non-additive genetic effects (heterosis) were estimated. The LSM heterosis of all strain crosses across all test environments was 4.3 %, and the cross that expressed the largest non-additive genetic effect showed a least square mean heterosis of 14 %. However, only seven out of the 22 crosses with significant heterosis performed better than the best pure strain, and the largest gain was then about 11%.

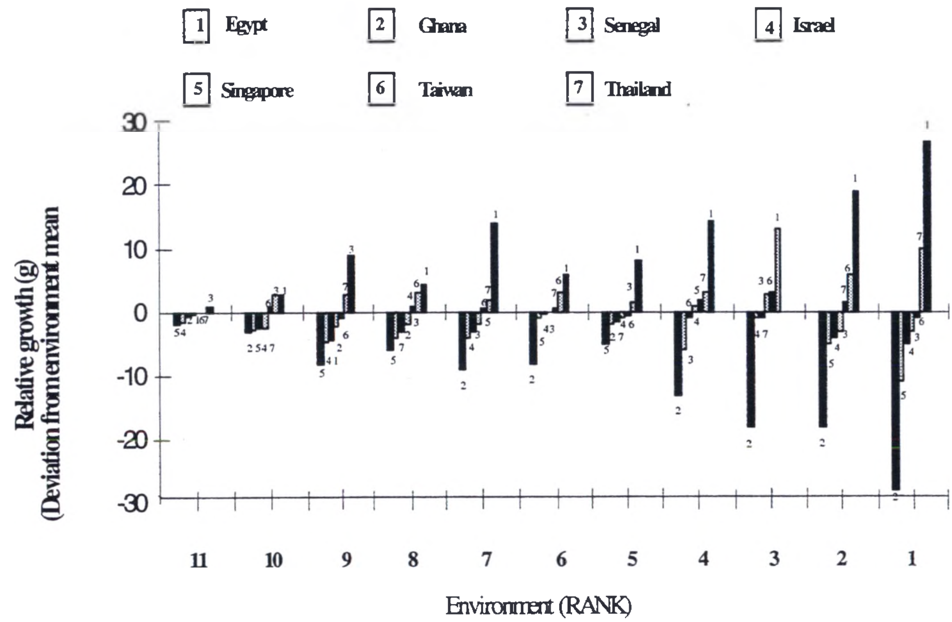

Figure 1. Relative growth performance of seven strains of Nile tilapia Oreochromis niloticus during the first generation Genotype x Environment test. Relative growth performance has been calculated as a deviation of least square mean of final body weights from the respective environment means (From Eknath et al. 1993).

Some strains performed better as sire strains and others as dam strains. It was concluded that specific crossing schemes may marginally improve growth performance and may show an increased sensitivity to GE interactions. Therefore, a regular selection program based on additive genetic performance will normally result in an improvement after a short period and may continue to improve without complications from laborious dissemination procedures and by a potential increased environment sensitivity of hybrids.

Building the base population and initiating selection: Based on their growth performance of 64 different strain combinations, individuals from the 25 best performing purebred and crossbred groups were selected to build a base population with a broad genetic base and initiate a selection program, with a combined family and within family selection strategy. Another major experiment was set up to estimate additive genetic parameters. 50 sires were mated with 150 dams in a hierarchical mating scheme. 25000 individually tagged fingerlings were grown for 90 days in seven test environments. The heritability estimates for body weight at harvest were consistent across test environments. The estimates based on sire and dam components of variance, respectively, were 0.23 and 0.53; heritability for survival based on sire component of variance was 0.08; and the half-sib correlation between body weight at harvest and survival was 0.2. The observed response after the first generation of selection in the synthetic GIFT strain, estimated as a difference between progeny of individuals with average breeding values and those from selected individuals, was 26%. In on-station trials, the synthetic GIFT strain was about 60% heavier at harvest than the 'Israel' strain (Eknath 1992). In every successive generation, about 20,000 individually tagged fingerlings from 120-183 selected full-sib families (within 100 half-sib families) have been evaluated in a variety of test environments. The genetic gain per generation across five generations of selection for growth performance has been about 12-17%. However, accumulated response to selection in relation to standard controls (progeny of individuals used in previous generations) and non-standard controls (progeny of founder stocks) was not fully expressed. This needs further investigation.

Strategic research in progress. Several strategic experiments are currently under way: evaluation of GE in specific target environments such as cages, rice-fish and earthen ponds; genotype x season interaction; procedures for developing late-maturing Nile tilapia; and procedures for a multi-trait selection plan involving growth, survival and late maturation.

REGIONAL ON-FARM TRIALS AND EARLY IMPACTS

The production potential of GIFT and existing Nile tilapia strains (referred as 'non-GIFT' strains because of their diversity of origins) were assessed through on-station and on-farm experiments in a range of aquaculture systems in Bangladesh, Peoples Republic of China, the Philippines, Thailand and Vietnam. Production per unit area or yield depends on stocking density, average weight at harvest and survival. After accounting for the wide heterogeneity of input use levels, production environments and other factors (using Seemingly Unrelated Regression Methods, Zellner, 1962), the percent change in average weight at harvest and survival were highly significant across different countries (Table 1). The magnitude of impact, however, varied according to the history of tilapia introductions and farmers' experience. Overall, the results indicated that the cost of production per unit of fish produced is lower for the GIFT strain than for the non-GIFT strains: more than 30% lower in Bangladesh and the Philippines; about 20% lower in Peoples Republic of China, Thailand and Vietnam (Table 2).

In the Philippines and Thailand, where about 80-90% of the tilapia production is marketed locally and the demand for tilapia is price elastic, both producers and consumers will benefit from technological interventions (such as the GIFT technology). As low-priced tilapia is consumed mainly by poor people whose demand is inversely related to price, the major portion of the consumers' benefit will go to poor consumers. In countries like Bangladesh, where tilapia fish farmers consume about 70% of their produce, the major economic gain from GIFT technology will accrue to the producers. In subsistence farming, the reduction in market price due to higher production has relatively little influence on producers' income.

Table 1. Percentage change in average weight at harvest and survival due to GIFT strain

Country	Average weight (g/fish)	Survival (%)
Bangladesh	+66.5	NS
China	+17.5	+ 3.9
Philippines	+36.8	+12.8
Thailand/Vietnam	+27.3	NS

Table 2. Yield (kg) and production costs (US$) of tilapia farming using GIFT and non-GIFT strains in earthen ponds (per ha.) and cages (per 100 m^2) in five Asian countries

	Bangladesh	China		Philippines		Thailand	Vietnam
	Pond	Cage	Pond	Cage	Pond	Pond	Pond
GIFT:							
Yield	**1593**	**3893**	**4645**	**236**	**1361**	**2829**	**743**
Cash costs	**463**	**4191**	**3548**	**168**	**1385**	**1510**	**427**
Cost of fish/kg	**0.29**	**1.08**	**0.76**	**0.71**	**1.02**	**0.53**	**0.58**
Non-GIFT:							
Yield	**896**	**3111**	**4275**	**153**	**912**	**2044**	**558**
Cash costs	**405**	**4191**	**3523**	**168**	**1375**	**1517**	**411**
Cost of fish/kg	**0.45**	**1.35**	**0.82**	**1.10**	**151**	**0.74**	**0.74**
% Change (GIFT / Non-GIFT)							
Yield	**+77.8**	**+25.1**	**+8.7**	**+54.2**	**+49.2**	**+38.4**	**+33.2**
Cash costs	**14.3**	**0**	**0.7**	**0**	**0.7**	**-0.5**	**3.9**
Cost of fish/kg	**-35.7**	**-20.1**	**-7.3**	**-35.2**	**-32.5**	**-28.0**	**- 22.0**

FUTURE OUTLOOK FOR THE SCIENCE OF FISH BREEDING.

The ICLARM selective breeding program is the first systematic attempt to apply the principles of animal breeding theory to tropical aquaculture in a developing country setting with the primary objective of demonstrating: (a) the importance of genetics in improving production efficiency, (b) methods and mechanisms for dissemination of results and products to reach targeted beneficiaries effectively, and (c) methods to estimate *ex ante* the potential benefits to a wide spectrum of aquaculture enterprises. Successful demonstration could mean not only better tilapia breeds for fish farmers but also new breeding procedures for use with other species.

The program has demonstrated the enormous gains in economic performance of farmed tilapia that are possible from a systematic selection program. The GIFT program has stimulated planning of and implementation of national fish breeding programs in Bangladesh, India, Indonesia and Vietnam. An International Network on Genetics in Aquaculture (INGA) has already been established in 1993 (Seshu et al. 1994). Thirteen countries in Asia and Africa are collaborating in research and exchange of genetic materials: Bangladesh, Peoples Republic of China, Cote d'Ivoire, Egypt, Fiji, Ghana, India, Indonesia, Malawi, Malaysia, the Philippines, Thailand, and Vietnam. ICLARM is the member-coordinator. Bilateral and multilateral research initiatives under the INGA have begun to include other fish species, especially the carps which account for most of the finfish production in Asia.

Fish breeding, unfortunately, appears to have come of age when overall funding from public sources to agricultural research has been declining. Advances in strategic research to improve productivity in aquaculture to close the looming gap in demand for and supply of food fish estimated at about 100 million mt by the year 2025 and also to establish a strong research base for the evolving tropical aquaculture industry will, therefore, depend on building strategic alliances with the private sector. Public funding to the GIFT program is scheduled to end in 1997. The strategic research and selective breeding program of Nile tilapia will continue in partnership with both private sector and public institutions through a non-stock non-profit research foundation established in 1997.

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