# Genetic Improvement with Specific Reference to Tilapia Genetic Resources in Africa and Their Use in Aquaculture-Potential Benefits and Risks

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## Abstract

In comparison to the rest of the world, aquaculture in Africa is fairly insignificant. The continent as a whole contributed a mere 0.9 per cent (404 571 t) to the total world aquaculture production in 2000. The African continent, however, exhibits considerable potential in terms of land and water and in regard to inland, coastal and offshore resources. Genetic improvement of tilapias has a role to play in order to increase aquaculture production. Promotion of such methods as selective breeding, hybridization, chromosome manipulation and gene transfer will help in improving aquaculture production. However, there are controversial issues that must be addressed so that genetic improvement should not compromise the conservation of biological diversity in the wild as well as in aquaculture. This is particularly important for tilapias in Africa where the species are indigenous and need to be conserved. Simple selective breeding of indigenous species within their natural zoogeographical zones would, therefore, offer great opportunity in African aquaculture, so that yield improvement is attained without causing significant genetic deterioration of the wild populations.

## Introduction

Fish is an important source of protein to more than one billion people in the world. It supplies about 30 per cent of the total protein intake for people in Asia, 20 per cent in Africa, and 10 per cent in Latin America. The fish industry employs 150 million people around the world and about 40 per cent of fish production is traded internationally. In the last decade, fish production has declined and the price of fish has gone up. In attempts to mitigate the price increase crisis, efforts are underway to develop methods of increasing fish production through aquaculture and to embark on sustainable management of wild stocks and the environment. This is important considering that the projected world demand for food fish for the year 2010 is estimated at 105 to 110 million t as against a production of 94 million t in 1997 (FAO 2000). The contribution of aquaculture towards world fisheries has increased from 11.4 per cent of the total catch in 1984 to 30.1 per cent of the catch by weight in 1998. In 1998 aquaculture contributed 16.9 per cent of the total finfish landings, 17 per cent of crustacean landings, 56.7 per cent of shellfish landings, and 87.5 per cent of the aquatic plant landings (Tacon 1999). The most important continents in terms of aquaculture production are Asia (74 per cent), Europe (11 per cent), North America (7 per cent), and South America (3 per cent). Developed countries such as those in Europe and North America have a higher contribution in terms of value because these countries are focusing more on the production of high value species. Demand for aquaculture products in North American and European markets has shown continuous growth of 10 to 15 per cent annually, particularly with regard to shrimp, salmon, trout, catfish, and tilapia.

In comparison to the rest of the world, aquaculture in Africa is fairly insignificant. The continent as a whole contributed a mere 0.9 per cent (404 571 t) to the total world aquaculture production in 2000 (FAO 2003). The African continent however exhibits considerable potential in terms of land and water, both with regard to inland, coastal and offshore resources. The expectations are that aquaculture development in Africa will show considerable increase over the medium to long-term due to the increasing demand in the world markets and the availability of resources in the continent.

Countries in the Mediterranean region produce 67 per cent (77 800 t) of the total production for Africa, with Egypt alone contributing approximately 34 per cent (42 000 t). The production in Sub-Saharan Africa amounts to 33 per cent (39 000 t) of the total production for Africa, or 0.2 per cent of world production. The most important countries in the Sub-Saharan region are Nigeria (16 600 t), Zambia (5 100 t), South Africa (5 000 t), Kenya (4 000 t), Tanzania (4 000 t), and Madagascar with (3 300 t) (Pedini and Shehadeh 1997). The main species cultured are tilapia, catfish, carp, cyprinids, mussels, oysters, shrimps, and seaweed.

Tilapia is a major aquaculture species in Africa and Asia and is a suitable species for increasing protein production, profits and the quality of nutrition of poor fish farmers and consumers.

The tilapia originated from Africa but has been spread all around the world in the tropical and subtropical areas because it is hardy, easy to grow, and can be fed with a range of different feeds. Although the tilapias have been distributed so widely outside their natural zoogeographical zone, little attention was given to the genetic improvement of farmed populations and the broodstock outside Africa which had been derived from very small founder populations and mismanaged, leading to genetic drift, inbreeding depression, and introgressive hybridization (Pullin and Capili 1988). The genetic problems of tilapias include: (i) loss of pure species through mismanagement of inter-specific hybridization in trying to produce all-male fry which grow faster than mixed sex populations (McAndrew 1993); and (ii) high level of inbreeding depression because primary collections of wild brood stock frequently consist of a small number of individuals. Kocher (1997) reports heterozygosity loss of less than 10 per cent in the farmed populations compared to the wild counterparts. Negative selection for growth rate has also occurred in the process of propagating many stocks.

Most African countries have erratic or only incipient aquaculture production. Aquaculture investment is generally minimal; there is still dependence on recruiting broodstock from the wild. Owing to small pond sizes and continuous drought regimes, the ponds generally dry out and seed or broodstock are easily lost. Consequently, new genetic material is collected from the wild. Hybridization in the ponds is also common to the extent that strains recruited into the farms easily interbreed. Genetic purity is quickly lost. The small pond sizes and limited supply of fingerlings have resulted in inbreeding in the aquaculture facilities. Farmers usually stock very few fingerlings with the intention that the fish will multiply during the grow-out period.

## Genetic Improvement in the Tilapias

Domestication of tilapias is still in the early stages, as the genetic resources have been poorly managed during the past 40 years of intensive and extensive culture systems (Kocher 1997). Several approaches have been used to improve the performance of tilapias in aquaculture and some that have immediate or near future applications in Africa are reviewed below.

### Selective Breeding

Selective breeding has been carried out on the tilapias and has now reached advanced stages. In other parts of the world, selection has been done for skin color, body conformation, fillet yield, growth rate, and cold tolerance (Behrends et al. 1982, 1990; Fitzsimmons 2000). In the Philippines, the WorldFish Center and other collaborating institutions carried out selective breeding programs on *O. niloticus* resulting in an improved strain called the GIFT strain, and it is being widely distributed in Asia. Protocols used to develop the GIFT strain are currently being used in Egypt, Cote d' Ivoire, Ghana and Malawi to improve local strains of *O. niloticus* and *O. shiranus*. This work is being carried out in collaboration with the WorldFish Center (Gupta et al. 2001). Small-scale strain comparisons were carried out from 1997 to1999 in Malawi where wild populations of *O. shiranus* grew faster than domesticated stocks. Microsatellite DNA analysis of the populations revealed that farm populations had very low genetic diversity compared to their wild counterparts, mean number of alleles 4.4±1.03 and 13.2±3.31, respectively, and there was introgression of *O. mossambicus* into the *O. shiranus* populations. *O. mossambicus* populations from several water bodies in southern Africa have been recruited for genetic improvement at the University of Stellenboch in the Republic of South Africa.

### Hybridization

Hybridization has been adopted as an approach to improve tilapia yields. The cultured tilapia species are closely related and readily produce viable hybrid crosses. Hybrids have also been produced to obtain all-male fry that grow better than mixed sex populations. McAndrew et al. (1988) indicated that one popular strain may contain genes from as many as four species. Heterosis has been observed for such traits as superior growth, feed conversion, cold or salt tolerance, and disease resistance.

## Chromosomes-set Manipulation

Chromosome-set manipulation techniques include polyploidy, gynogenesis and androgenesis. These have been applied in fish improvement programs although gynogenesis and polyploidy have been widely applied in tilapia aquaculture compared to androgenesis which has had limited application.

## Gynogenesis

Gynogenesis or all-maternal inheritance is a chromosome manipulation technique that ensures the exclusive inheritance of the maternal genome. The egg develops without any genetic contribution from a male parent because the genetic material of sperm is inactivated by exposing the sperm material to radiation (for example x-rays, ã-rays and ultraviolet light) or to chemical mutagens such as toludine blue, dimethylsulfate or tryplavine, without affecting its functional potential to fertilize or activate egg development. The egg development initiated by irradiated spermatozoa is a haploid gynogenetic zygote. The diploidy state can be restored by subjecting the haploid zygote to thermal, chemical or hydrostatic pressure shock treatments (Romana 1988).

If the pressure shock treatment (heat or cold shock) or chemical treatment (cytochalasin B, colchicines, and polyethylene glycol) is applied soon after fertilization to suppress ejecting of second polar body meiotic gynogenes are obtained. Mitotic gynogens are produced by late shock treatment to suppress the first mitotic division, allowing restoration of diploidy. Meiotic gynogens are about 50 per cent inbred due to crossing-over and the recombination, while mitotic gynogens are 100 per cent inbred and can be used for the production of clonal lines (Purdom 1993; Owusu-Frimpong et al. 1997). The gynogenetically induced inbred lines of tilapia are developed for purposes of hybridization to fix desirable production traits.

Production of a single sex group, which can be achieved by manipulating developing gametes or embryo, provides the advantage of exploiting the sexual growth differential phenomenon whereby male tilapias grow faster than female tilapias. The manipulation would include denaturing the DNA in gametes followed by chromosome-set manipulation or hormonal sex-reversal and subsequent breeding. Genetically male tilapia can be turned into females through estrogen treatments. The genetic females when mated with normal males produce a group of all-male tilapia that grow faster and have less unwanted mating than mixed sex stock.

## Polyploidy

This technique produces polyploids, triploid or tetraploid organisms that do not invest their energy into reproduction because they do not develop effective reproductive organs. Ploidy manipulation employs the same physical and chemical treatments used in the diploidisation phase of gynogenesis. Alternatively, triploidy can be obtained by mating normal diploid fish with tetraploids. Their main advantage is that they are sterile. In tilapia, triploidy has been advantageous in that it retards gonadal development. Hence, there is an absence of uncontrolled reproduction, which causes stunted growth (Bramick et al. 1995).

## Genetic Engineering

Genetic engineering and the production of transgenic organisms have become an active area of research and development in aquaculture. In tilapia, transgenics that contain the exogenous growth hormone (GH) gene construct derived from Chinook Salmon have demonstrated growth enhancement (Rahman and Maclean 1997). The transgenic tilapia grows three times larger than their non-transgenic siblings in a period of seven months. Studies of transgenic technology in tilapias have demonstrated great potential of improving aquaculture production by growing genetically modified tilapias.

## Marker-assisted Selection

Use of genetic makers to identify loci that control quantitative traits (QTL) and develop superior strains through marker-assisted selection is still in its early stages in tilapia improvement programs. Work on developing a linkage map in tilapia has been carried out at the University of New

Hampshire, offering an opportunity to track and select desirable genes from the map.

## Potential Benefits and Risks

Genetic improvement offers an enormous opportunity for increasing aquaculture production in Africa. It, therefore, implies that each of the techniques discussed above has potential benefits although experience has shown that besides the benefits there are inherent risks associated with them as well.

### Selective Breeding

Selective breeding offers great opportunity for aquaculture production in Africa. Most of the tilapia species cultured in Africa have not been adequately domesticated, hence, the application of selective breeding in the domestication process can improve the performance of the strains. The fifth generation GIFT strain of *O. niloticus* is reported to grow 85 per cent faster than other farmed strains and can be grown without commercial feed in extensive systems (Eknath and Acosta 1998). Application of similar protocols on the stocks within Africa would improve the performance of local tilapias. The risks from selective breeding are that it takes a long time to improve a strain and it is costly; consequently, such programs are likely to be abandoned in the African setting where funding for genetic research is limited and labor turnover is high as trained personnel change jobs in search of better remuneration. Instead of countries concentrating on developing their own native genetic resources, there is a tendency to import improved strains developed elsewhere. For instance, *O. niloticus* has been introduced into some African countries such as Zimbabwe and Zambia because the species grows faster than indigenous species. Owing to poor management, some of these introduced strains have escaped into the wild and hybridized with indigenous species. This, therefore, brings in ecological risks whereby the introduced species cross with indigenous ones and produce unbalanced sex ratios. Crossing a female *Tilapia tholloni* with a male *O. mossambicus* yields 100 per cent females and crossing female *O. spirulus* with male *O. leucostictus* yields 98 per cent males (Agnese et al. 1998). There are several cases where farmed populations have escaped into the wild but the results of hybridization are not easily observed. In cases where genetic markers have been used, it has been observed that the genetic purity of the indigenous stock has been lost. In Lake Ayami in Cote d'Ivoire, *T. busumana* and *T. discolor* have been reduced in numbers and even disappeared in catches. Instead, they have been replaced by *Sarotherodon melanotheron*, an introduced species (Agnese et al. 1998). Limited research facilities have also resulted in the risk of deteriorating genetic diversity because only a few individuals are recruited as founder stocks, causing inbreeding. The risk is, however, tolerable in countries where indigenous species are stocked because there is a tendency to recruit wild genetic materials on a more regular basis as the stocks are easily wiped out by drought, floods or predators.

### Hybridization

Hybridization can be adopted as a genetic improvement approach to increase performance of the progeny through heterotic and non-heterotic effects. The heterotic effect is increased performance of the progeny above the average of the parents as a result of the simple combination of parental genotypes (FAO/UNEP 1981). Most fish culturists in developing countries breed superior individuals from unrelated strains in order to bring new genes into a selection program. The $F_1$ hybrids are normally propagated as parental stocks with the assumption that the observed improved growth will be passed on to the subsequent generations. Unfortunately, this does not occur due to segregation and consequent hybrid breakdown in the $F_2$ generation. Most of the hybrids produced in aquaculture in Africa are unplanned, hence they have not been monitored adequately. For instance in Malawi, hybrids between *O. shiranus chilwae* and *O. shiranus shiranus*, and between *O. shiranus* sp and *O. mossambicus* have been produced unnoticed (Ambali et al. 1999).

If hybridization is chosen as an approach for improving the performance of the indigenous population, there should be well-established genetic characterization records in order to monitor the long-term purity of the parental lines. A great deal of effort is, however, required to breed and maintain these parental lines, yet developing countries cannot afford the costs involved.

### Genetic Engineering

There has so far been no commercial farming of genetically engineered tilapias in aquaculture in Africa. However, in places where transgenics have been grown in the laboratory, they have shown higher growth than non-transgenics. Prospects of genetically modified (GM) tilapias being introduced in aquaculture are high because of the need to increase food production in developing countries in Africa and Asia. The concerns being expressed by anti-GMs lobbies may wane with time as the benefits of growing GM tilapias will outweigh the risks involved.

A potential risk of using genetic engineering for improving tilapia populations is that transgenics would make individuals less fit than their wild counterparts by affecting such traits as juvenile survival. But this is only a speculation.

### Chromosomesset Manipulation

The advantage of chromosomes set manipulation is that single sex individuals can be produced which may have better growth than mixed sex populations. Production of ploidy fish requires a proper understanding of ploidy manipulation and parental genome inactivation techniques.

The risk of the technique is that it is difficult to attain 100 per cent sex-reversal. The technique has, therefore, met with failure. The other problem is that of obtaining a large number of eggs prior to fertilization, and this is an impediment to large-scale commercial tilapia culture.

### Marker-assisted Selection

In marker-assisted selection, it takes a short period to improve performance of individuals in a population as compared to conventional breeding. The problem is the high costs involved in developing linkage maps.

## Way Forward

Genetic improvement of tilapias has a role to play in order to increase aquaculture production. The lack of suitable species has been identified as one of the key factors that have affected the adoption of aquaculture in most African countries much as environmental conditions are favorable and water is available. Promotion of such methods as selective breeding, hybridization, chromosome manipulation and gene transfer will help in improving aquaculture production. However, there are controversial issues that must be addressed so that genetic improvement should not compromise the conservation of biological diversity in the wild and in aquaculture. This is particularly important for tilapias in Africa where the species are indigenous and need to be conserved. Simple selective breeding of indigenous species within their natural zoogeographical zones would, therefore, offer great opportunity in African aquaculture so that yield improvement is attained without causing significant genetic deterioration of the wild populations. Modern molecular techniques are becoming more affordable as laboratory protocols become more refined. The DNA probes, especially microsatellite DNA, would be employed in the breeding programs to establish records of family relationships and pedigrees and determine the genetic stock structure of the natural populations.

The introduction of superior strains may not be the most appropriate approach in most African countries where aquaculture facilities are poor and the fish easily escape into the wild.

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