Potential of genetics for aquaculture development in Africa

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Abstract

Aquaculture in Africa is fairly insignificant by world standards and accounts for a mere 0.4 per cent of global aquaculture production. The application of genetics can play an important role in efforts to increase aquaculture production in Africa through methods such as selective breeding, hybridization, chromosome manipulation and use of YY "supermales". Other issues that need to be addressed are limited genetic research facilities, funding, human capacity and suitable species for aquaculture.

Introduction

In comparison to the rest of the world, aquaculture in Africa is insignificant. The continent as a whole contributed a mere 0.4 per cent to the total world aquaculture production from 1984 to 1995 (Hecht 2000). Although currently undeveloped, aquaculture is expected to play an important role in future by providing food and employment for people in Africa (Miller et al. 2002).

The general characteristics of aquaculture production, its constraints and development potential differ considerably in North Africa and the sub-Saharan region. North Africa has a far greater potential. In Egypt, for instance, aquaculture has been practiced extensively for a long time, while in other countries of the continent it is a relatively new technology and has not yet been recognized as a consolidated food production sector in national economies. In terms of physical potential, North Africa has suitable locations that have been developed for farming of marine and estuarine species for export to the European markets. The new farms use more sophisticated, intensive production technologies that have been imported from Mediterranean countries. On the other hand, aquaculture in sub-Saharan Africa has been oriented to domestic markets and is mostly practiced by small-scale farmers. Although there is a physical potential for expansion of aquaculture in this region, factors such as the novelty of aquaculture, the generally poor economic conditions in many countries, and the relative paucity of entrepreneurial skills and credit facilities hamper its development (FAO 1997).

Challenges and constraints

There is potential for a significant increase in aquaculture production in Africa through sustainable intensification and horizontal expansion into inland waters and coastal areas. Positive growth in aquaculture can be realized if a number of constraints and challenges facing the aquaculture sector are addressed. These include: (i) lack of localized knowledge systems on aquaculture among African farmers; (ii) prevalence of foreign aid programs organized on a top-down basis with inconsistent, short-term goals and excessive dependence on donor funded aquaculture development programs; (iii) low allocation for aquaculture development in national budgets; (iv) wholesale importation of traditional crop agriculture practices into aquaculture, such as seed recycling; (v) poor or slow growth of cultured species; (vi) poor broodstock management; (vii) loss of genetic diversity in culture system; (viii) contamination of the wild and indigenous gene pool; (ix) lack of baseline genetic data; and (x) poor species identification (Pullin and Capilli 1988). This paper discusses the potential of genetics in addressing some of the constraints and challenges identified above.

Several species are used in aquaculture in Africa (Table 1). The major ones are: *Oreochromis niloticus*, *O. aureus*, *Sarotherodon galilaeus* and *Tillapia zilli* in North and West Africa; *O. mossambicus, O. shiranus, T. rendalli, Clarias gariepinus (*African catfish*)*, and rainbow trout (*Salmo gairdneri* and *S. trutta*) in southern Africa; *S. melanotheron* is a relatively new, but important species in West Africa. The use of genetics in aquaculture development on the African continent has mainly focused on tilapia culture. Hence, the discussion in this paper uses tilapia to illustrate its case.

The tilapias (Cichlidae), some 870 species (Skelton 1993), are the major cultured species in Africa. They are suitable for culture and increasing the availability of protein and the quality of nutrition of poor fish farmers and consumers. Species of the genera *Oreochromis*, *Sarotherodon* and *Tilapia* have been widely exploited in aquaculture and natural fisheries. Within the *Oreochromis* genus, *O. mossambicus*, *O. niloticus* and *O. aureus* are considered the most important species for aquaculture.

Domestication of tilapias in Africa is still in the early stages. The genetic resources have been poorly managed during the past 40 years of intensive and extensive culture (Kocher 1997). Broodstock used in seed production are generally from the wild. Owing to small pond sizes and frequent droughts, the ponds generally dry out and seed or brood stock is easily lost. Hybridization and inbreeding in the ponds is also common as the strains recruited into the farms easily interbreed and genetic purity is lost. Kocher (1997) reports of a genetic survey that revealed heterozygosities of less than 10 per cent in several strains of farmed tilapia populations compared to their wild counterparts.

Genetic approaches used

Several approaches have been used to improve the performance of tilapias in aquaculture and these include genetic manipulation. These techniques have been very successful in other countries and seem to indicate an opportunity for increasing aquaculture production in Africa.

Selective breeding

In Africa, selective breeding of tilapias has been mainly aimed at increasing their growth rate so that a farmer can realize quicker and higher yields. In other parts of the world, selection has also been done for skin color, body conformation, fillet yield and cold tolerance (Behrends et al. 1982, 1990; Fitzsimmons 2000). Protocols used to develop the GIFT strain *O. niloticus* by the WorldFish Center and its partners in the Philippines and Norway are currently being used in national research institutions in Côte d'Ivoire, Egypt, Ghana and Malaŵi to improve local species and strains of tilapias through selective breeding (Gupta et al. 2001). Selective breeding can ameliorate the problem of poor or slow growth rate among cultured fish species. Most of the tilapia species cultured in Africa have not yet been adequately domesticated and, therefore, the application of selective breeding in the domestication process can improve the performance of the strains. The GIFT strain *O. niloticus* is reported to grow 85 per cent faster than other farmed strains in the Philippines, have better survival rates, and can be grown without commercial feed in extensive systems (M. Gupta personal communication). Application of similar protocols on the stocks within Africa would improve the performance of local tilapias. However, selective breeding takes a long time to improve a strain and is expensive. The risks for selective breeding programs are that they are unlikely to receive long-term financial support from governments and donors for genetic research, and labor turn-over is high as trained personnel change jobs in search for better remuneration.

Hybridization

Hybridization has been used as a technique of improving yield of tilapias. The cultured tilapia species are closely related and readily produce viable hybrids. McAndrew et al. (1988) indicate that one popular strain may contain genes from as many as four species. Hybrids have also been produced to obtain all-male fry that have better growth than mixed sex populations.

Most of the hybrids produced in aquaculture in Africa are unplanned and, hence, they have not been monitored adequately. For example, in Malaŵi, hybrids between *O. shiranus chilwae* and *O. shiranus shiranus*, and *O. shiranus* sp and *O. mossambicus* have been produced unwittingly (Ambali et al. 1999). There is a tendency to import improved strains developed from elsewhere, instead of concentrating on developing native genetic resources, e.g., *O. niloticus* has been introduced into Zambia and Zimbabwe because the species grows faster than indigenous species. Some of these introduced strains have escaped into the wild and hybridized with indigenous species because of poor management. In the Limpopo river in South Africa, *O. niloticus* has produced hybrids with *O. mossambicus* (Brink et al. 2002). Ecological risks have been reported from hybridization in some countries. While hybridization may bring about hybrids with a combination of desirable traits from different groups, the possibility of sterile and non-sterile hybrids may lead to introgression and breakdown of genetic distinctiveness (Penman 1999).

Table 1. Indigenous fish farmed in Africa

Species	Countries
Anguilla anguilla	Algeria, Morocco, Tunisia
Chrysichthys nigrodigitatus	Côte d'Ivoire, Nigeria
Clarias anguillaris	Burkina Faso, Egypt
Clarias gariepinus	Cameroon, Central African Republic, Ghana, Guinea, Lesotho, Malaŵi, Mali, Nigeria, Rwanda, South Africa, Swaziland, Tanzania, Zambia
Dicentrarchus labrax	Algeria, Egypt, Morocco, Tunisia
Heterotis niloticus	Gambia, Mali, Nigeria
Lates niloticus	Nigeria
Liza ramada	Tunisia
Mugil cephalus	Egypt, Tunisia, South Africa
Oreochromis andersonii	Zambia
Oreochromis aureus	Côte d'Ivoire
Oreochromis macrochir	Zambia
Oreochromis mossambicus	Malaŵi, Mozambique, South Africa, Swaziland
Oreochromis niloticus	Burkina Faso, Burundi, Cameroon, Central African Republic, Congo, Côte d'Ivoire, Egypt, Gabon, Ghana, Kenya, Liberia, Mali, Mozambique, Niger, Rwanda, Sénégal, Sierra Leone, Sudan, Tanzania, Togo, Uganda, Zambia
Oreochromis shiranus	Malaŵi
Pomatomus saltator	Tunisia
Sarotherodon melanotheron	Côte d'Ivoire
Solea solea	Algeria, Tunisia
Sparus aurata	Algeria, Egypt, Morocco, Tunisia
Tilapia rendalli	Malaŵi, Swaziland, Tanzania, Zambia
Tilapia zilli	Uganda

Source: FAO (1997); FishBase (1998)

Table 2. Genetic approaches used in Africa

Method	Countries
Selective breeding	Côte d'Ivoire, Egypt, Ghana, Malaŵi, Sénégal, South Africa
Hydridization	Côte d'Ivoire, Malaŵi, Egypt (unplanned)
Molecular marker	Côte d'Ivoire, Egypt, Ghana, Malaŵi, Nigeria
Gynogenesis	South Africa, Zambia
Genetic engineering	None

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). These introgressive hybridizations have led to loss of genetic purity of the indigenous stocks (Agnese et al. 1998; Ambali et al. 1999). In lake Ayami in Côte d'Ivoire, *T. busumana* and *T. discolor* have been reduced in numbers and even disappeared in catches. They have been replaced by *S. melanotheron*, an introduced species.

If hybridization is chosen as a technique for improving the performance of the indigenous population in aquaculture, there should be well-established genetic characterization records in order to monitor the long-term purity of the parental lines. Molecular markers can be employed to generate baseline genetic data of indigenous populations, which can be used later to check if there is contamination of wild and indigenous gene pools through hybridization. A great deal of effort is required to breed and maintain these parental lines, and most African countries cannot afford the costs involved.

Molecular marker-assisted selection

Use of genetic makers to identify loci that control quantitative traits (QTL) and to develop superior strains through marker-assisted selection is still in the early stages in tilapia improvement programs. Work on developing linkage maps for tilapia has been carried out at the University of New Hampshire, offering opportunity to track and select desirable genes from the map (Kocher 1997). Theoretically, marker-assisted selection takes a shorter period to improve performance of individuals in a population as compared to conventional breeding. The only constraint to the use of this technique is the cost involved in developing linkage maps.

Although feasibility of marker-assisted selection is yet to be demonstrated in Africa, molecular markers such as Randomly Amplified Polymorphic DNA (RAPD), Restriction Fragment Length Polymorphism (RFLP), and microsatellites have been employed to generate genetic data for assessing genetic diversity, population structure, and migration among fish populations. For example, small-scale strain comparisons were carried out in Malaŵi during 1997-99 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 (Ambali et al. 1999). *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. Analysis of the genetic structure and diversity provided evidence for high levels of variation within and between the (12) populations (Brink et al. 2002). French scientists and the Institute of Aquatic Biology in Ghana have subjected West African cultured species like *S. melanotheron* to genetic investigation using various molecular markers. Some of the results showed that populations of *S. melanotheron* from Sierra Leone, Sénégal, Liberia, Ghana, Togo, Côte d'Ivoire, Benin and Congo-Brazzaville share a common ancestry (J.F. Agnése personal communication to W. Changadeya).

Gynogenesis

"YY supermales" have been produced and assessed in South Africa through a collaborative project between the University of Stellenbosch (RSA) and the University of Wales Swansea (UK). Significant progress was made in the production of genetically male tilapia (YY males) in *O. mossambicus* with 20 YY males identified by the end of the project (Brink et al. 2002). *O. niloticus* YY males were introduced at Kafue fish farm in Zambia from the University of Wales Swansea (Jamu and Brummett 2002). Baseline data collected during the trials in South Africa suggest that gynogenesis increased the yield and can thereby make a meaningful contribution to improving livelihoods from aquaculture (Brink et al. 2002).

Other genetic approaches

Three genetic techniques, namely, selective breeding, hydridization, and molecular markers application have been used in Africa (Table 2). Other genetic techniques have been successfully applied elsewhere to improve the performance of cultured fish. Such techniques may possess a potential for improving aquaculture production, but have not been widely tried.

Polyploidy

This technique produces sterile polyploid, triploid or tetraploid organisms that do not invest energy into reproduction. 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, but there is no increase in the growth rate. In tilapia, triploidy retards gonadal development and, hence, uncontrolled reproduction that causes stunted growth (Bramick et al. 1995). This technique has been employed in rainbow trout (Thorgaard 1992) and the Pacific oyster (Guo et al. 1996), but may not be feasible in several species of fish due to the low viability of induced tetraploids (Cassani et al. 1990; Cherfas et al. 1993).

Genetic engineering

Genetic engineering and production of transgenic organisms has 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). Transgenic tilapia grow three times more than their non-transgenic siblings in a period of seven months. Transgenic common carp, catfish, Coho salmon, and tilapia have been produced and are being tried for commercial use (FAO 1997). Although transgenic fish have demonstrated increased growth and have the potential to raise aquaculture production, it will be some time before they will be commercially farmed because several issues against transgenic products must be addressed. These include: (i) transgenic fish may escape into the wild and disrupt natural populations; (ii) the "transgenes" could be passed on to wild relatives; and (iii) consumers may not accept genetically modified fish.

Constraints to application of genetics

Application of genetics to aquaculture in Africa has been constrained by a number of factors.

Limited research facilities. Research facilities are limited and mostly state-owned in almost every African country where aquaculture is practiced. Many African universities also do research on aquaculture, with technology development and transfer coming mainly through donor-funded projects. Among the many aquaculture research centers in Africa, only a few are known for genetics research, namely, the WorldFish Center's regional center in Abbassa, Egypt, and the University of Stellenbosch, Republic of South Africa. The availability of machinery and facilities for conducting genetic research is dependent on the donor community as national governments are unable to provide the funds and because research is given a low priority in most national budgets.

Limited funding. Although the majority of aquaculture systems in Africa were introduced through technology development and transfer projects, most research, development, and extension centers are non-functional at present. Even when there are funds for research in aquaculture, only limited amounts are allocated to research in genetics (Yapi-Gnaoré 2002).

Limited skills. Capacity to conduct aquaculture genetics research exists in most African universities, but very few experts are permanently based in research stations, which are usually government owned. It would be fruitful to enhance collaboration between universities with the capacity for genetics research and government departments with the infrastructure for undertaking research and a mandate to increase production. In addition, there is a need to train government personnel in aquaculture genetics.

Crop agriculture transplanted to aquaculture. In most African countries, aquaculture is new compared to traditional agriculture. Most fish farmers are smallholder farmers who own small pond facilities on their farmlands. These farmers tend to transfer traditional practices from crop agriculture, such as seed recycling, into aquaculture and do not fully appreciate the importance of acquiring genetically improved strains. In areas where aquaculture is not on a commercial scale, the market for good quality fingerlings and broodstock is virtually nonexistent. This has compromised proper broodstock management.

Lack of suitable domesticated species. In Africa, *O. niloticus* appears to be the best candidate species, but it is not widely domesticated, except in North Africa. The introduction of non-indigenous species has led to hybridization with other related species and the production of unplanned hybrids. The management of introduced and translocated species is poor due to the lack of proper broodstock management and containment facilities. The introduction of the Nile perch (*Lates niloticus*) in lake Victoria led to the elimination of about 65 per cent of the endemic haplochromine fauna and caused the loss of about 200 taxa from the lake (Goldschmidt et al. 1993; Shumway 1999). Suitable domesticated species that could be genetically improved so as to enhance their performance in aquaculture should be identified for different regions. This process should be done simultaneously with the development of broodstock management protocols suitable for the specific species.

Capacity building

Aquaculture in Africa can make use of various technologies that have been used in other countries in North America and Asia. Capacity building through technology transfer is required. This is a dynamic process that involves creating, mobilizing, utilizing, enhancing or upgrading, and adjusting the existing capacities of individuals and local communities, institutions and the country-level policy framework in which individuals and institutions grow, operate and interact with their internal and external environment (Ngoile and Sarunday 2002). Aquaculture scientists from Africa should be trained in specific technologies in countries that have experience in employing these technologies. Since technology transfer is a continuous process, the networking with research institutions outside the continent has to be continuous so that Africa is not left behind in technology. Linkages should also exist between aquaculture institutions in Africa and international facilities such as the WorldFish Center's facility in Egypt and the International Network on Genetics in Aquaculture (INGA). Though isolated, the existing technical capacity in various aquaculture centers in Africa should be recognized and shared among African scientists through networking and other linkages. There should be linkages among universities, among research stations, and between research stations and universities.

Way forward

Genetic improvement has a role to play in increasing aquaculture production in Africa. The lack of suitable species has been identified as one of the key factors that have constrained the adoption of aquaculture in most African countries, even though environmental conditions are favorable and water is available. Promotion of such methods as selective breeding, hybridization, and chromosome manipulation will help in improving aquaculture production. The DNA probes, especially microsatellite DNA, should be employed in breeding programs to establish records of family relationships and pedigrees, and determine the genetic stock structure of the natural populations. Genetic improvement should not compromise conservation of biological diversity in aquaculture and in the wild. This is particularly important for most aquaculture species in Africa as these are indigenous and need to be conserved. Simple selective breeding of indigenous species within their natural zoogeographical zones would provide yield improvement without causing significant genetic deterioration of the wild populations. Import of genetically improved strains or other strains that do well in Asia should be discouraged, while encouraging improvement of native species. Lessons can be drawn from other continents, e.g., Europe where Atlantic salmon taken from the Baltic Sea to Norway infected Norwegian Atlantic salmon with a parasite to which it had no resistance (Bartley and Martin 2002).

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