A review of global tilapia farming practices

Modadugu V. Gupta and Belen O. Acosta

WorldFish Center
P.O. Box 500 GPO, 10670, Penang, Malaysia

Tilapia, that is native to Africa and Middle East, has emerged from mere obscurity to one of the most productive and internationally traded food fish in the world. The farming of tilapias in its crudest form is believed to have originated more than 4,000 years ago from Egypt. The first recorded scientifically oriented culture of tilapia was conducted in Kenya in 1924 and soon spread throughout Africa. Tilapia was later transplanted and became established as a potential farmed species by the late 1940s in the Far East and a decade later spread in the Americas.

The last three decades have seen significant developments in farming of tilapias worldwide. In view of the increasing commercialization and continuing growth of tilapia industry, the commodity is not only the second most important farmed fish globally, next to carps but is also described as the most important aquaculture species of the 21st century (Shelton 2002). The fish is being farmed in about 85 countries worldwide (FAO 2002) and about 98% of tilapia produced in these countries is grown outside their original habitats (Shelton 2002). The main culture industries are in the Far East but they are increasingly being farmed in Caribbean, Latin America and recently, in temperate countries where warm water through artificial means (thermal effluents or geothermal springs) are also available.

Development of technologies that are significant to tilapia farming

Tilapias are known to have been an important component of subsistence fisheries for thousand of years within their native range but this commodity has gained prominence in farming and food status not within their endemic areas but elsewhere as an exotic species. The farming of tilapia outside Africa began in Asia with the introduction of Mozambique tilapia (*Oreochromis mossambicus*) but early experience in culture of the species was met with failure due to its undesirable characteristics and production of small, low value fish at harvest. Success in tilapia farming began in the latter half of 20th century after introductions of better performing tilapia species from Africa and development of techniques to manage unwanted reproduction.

In populations of tilapia, males grow faster and are more uniform in size than females. For this reason, the farming of monosex populations of tilapias, which is achieved either by manual sexing, direct hormonal sex reversal, hybridization or genetic manipulation, has been reported as a solution to the problem of early sexual maturation and unwanted reproduction.

Manual sexing, which entails elimination of females based on sexual dimorphism observed in the urogenital papilla, is simple but is time consuming, requires qualified personnel and usually results in 3-10% errors.

Hybridization has been studied extensively mainly to improve commercial traits and to control unwanted reproduction in ponds. Early research work of Hicking (1960) on hybridization between various species of *Oreochromis* (*O. urolepis*, *O. hornorum* and *O. mossambicus*) resulting in all male hybrids was pivotal in subsequent investigations that led to important milestones in tilapia farming (Lazard 1996; Shelton 2002). Subsequent interspecific crossing and various culture methods for commercial application were tried and it was found that crossing male *O. hornorum* or *O. aureus* with *O. mossambicus* or *O. niloticus* also produced all male or nearly all-male progeny (Shelton 2002). Despite these developments, hybridization did not effectively solve the problem of unwanted reproduction mainly due to difficulty in sustaining production of all-male hybrids. This is most likely caused by insufficient care in keeping the broodstock segregated by sex and species and in preventing introduction of hybrids into the broodstock ponds.

In view of limitations described above in hybridization, masculinization of the entire tilapia populations through hormonal sex reversal was sought. The technique, which involves the addition of steroids in feeds for a short period during the fry stage, proved to be easily applied, relatively consistent in producing nearly all male populations and could be repeated in various country situations by farmers. The use of this technique however has not been fully accepted in some countries due to environmental and social constraints; for example, the metabolism and the effects on the environment of the degradation products of synthetic androgen are not yet fully understood in fish (Baroiller 1996). In the United States, the use of hormones in sex reversal is currently under evaluation by the Food and Drug Administration (Chapman 2003).

The recently developed technique for obtaining monosex population is by producing ‘supermales’ through genetic manipulation. Based on the theory of predominantly monofactorial sex determination, it has proved possible to manipulate sex ratio using a combination of sex reversal and progeny testing to identify sex genotypes. In a breeding program in *O. niloticus*, Mair et al (1997) developed a technology that produces genetically male tilapia (GMT) with an average sex ratio of >95% male and 40% increase in yield.

The development of Genetically Improved Tilapia (GIFT) technology that is based on traditional selective breeding and is meant to improve commercially important traits of tropical farmed fish is a major milestone in the history of tilapia aquaculture. Through combined selection technology, the GIFT program achieved 12-17% average genetic gain per generation over five generations and cumulative increase in growth rate of 85%. in *O. niloticus* (Eknath and Acosta 1998).

Species and strains for culture

There are about 70 species of tilapias, most of them native to Western rivers of Africa (Anon 1984). Of these, nine species are used in aquaculture worldwide (FAO 2002) (Table 1). However, tilapia production is concentrated mainly on Nile tilapia (*O. niloticus*), Mozambique tilapia (*O. mossambicus*) and Blue tilapia (*O. aureus*). Of these three species *O. niloticus* has for many decades been responsible for the significant increase in global tilapia production from freshwater aquaculture and accounted for about 83% of total tilapias produced worldwide (FAO 2002) (Fig. 1). Mair (2002) however argued that production data on *O. niloticus* may not accurately represent the correct figure. In China, for example, it is estimated that as much as 60% of the species produced is in fact production of an *O. niloticus* x *O. aureus* F1 hybrid. Although most of its reported productions are from feral populations, *O. mossambicus* is the next predominant tilapia species, contributing about 4% of the world's total tilapia aquaculture production.

Pullin (1983) compared various tilapia species with culture potential and suggested that research efforts be concentrated on *O. niloticus* and *O. aureus*. Shelton (2002) claimed that while the latter is still used to produce the hybrids, it has been effectively left behind as *O. niloticus* has taken the lead as the principal species for culture in many parts of the world. This species is the most favored by farmers due to its suitability for farming in a wide array of culture environments/ systems, ranging from extensive, low-input pond culture to intensive recirculating systems. The other species that are gaining recognition because of their adaptability to certain conditions are *O. aureus* for colder waters and *O. spilurus* for saline waters.

The Red tilapia hybrids, produced first time in Taiwan through the interspecific cross of *O. mossambicus* albino and *O. niloticus*, are providing the '3rd generation of tilapias' combining favored colors with other desirable features of tilapias (Anon. 1984). This fish has gained increasing preference of commercial farmers in some countries because of their reddish color liked by consumers and their resemblance to premium marine species such as sea bream (*Chrysophrys major*) and red snapper (*Lutjanus campechanus*). In terms of performance, Alceste (2000) claimed that Red tilapias are suitable for brackishwater and seawater culture because of salinity tolerance of the parental species, known to be moderately (*O. niloticus* and *O.*

Table 1. Commercially important tilapias and their characteristics (modified from Mair 2001)

Species	Common name	Characteristics
Oreochromis niloticus	Nile tilapia	Performs well in tropical/subtropical areas; sexual maturity in ponds reach only at age of 5-6 months; suitable for culture in wide range of farming system (extensive to highly intensive system; monoculture and polyculture); high consumer and producer acceptance; least tolerant to cold water
O. aureus	Blue tilapia	Most cold resistant species (can tolerate low temperature of 8-9 ^{o}C); suitable for culture in countries with seasonal changes in temperature; sexual maturity in ponds reach at age of 5-6 months; commonly used in hybridization for production of monosex tilapias
O. mossambicus	Mozambique tilapia	High saline tolerance (grows well up to 20ppt); early reproduction (attains sexual maturity at 8-9 cm) and high fecundity; poor aquaculture potential except when used for hybridization
O. spilurus	None	Saline tolerant; used in seawater cage culture
O. hornorum (Tilapia urolepis)	Zanzibar tilapia	Can tolerate brackishwater
Sarotherodon galilaeus	Gallilee tilapia	Saline tolerant; slow growth
S.melanotheron	Black-chinned tilapia	Wide salinity tolerance (0-45 ppt but prefers 10-15 ppt; of interest for brackishwater aquaculture; used for extensive aquaculture in some parts of Africa
Tilapia rendalii	Redbreast tilapia	Feeds on macrophytes
T. zillii	Redbelly tilapia	Grows well in full strength seawater
Red tilapia hybrids[1]	Hybrid origins	Suitable for brackishwater and seawater because of salinity tolerance of parental species; commonly used for intensive culture (cages, tanks, raceways) but also reported to be suitable for farming under low-input conditions; initial high consumer acceptance due to color; sometimes exhibit low fecundity

[1]*produced through crossbreeding of albino or mutant-reddish orange* O. mossambicus *(a normally black species) with other species, including* O. niloticus, O. aureus and O. hornorum*)*

aureus) to highly euryhaline (*O. mossambicus* and *O. hornorum*). Red tilapia hybrids are most commonly used in intensive aquaculture operations but recent reports indicate that they also have potential for culture under low-input farming.

While tilapias in general are known for their relative ease of cultivation and other attributes, their growth and other production traits are largely influenced by genetics. Popma and Lovshin (1996) reported that males of pure strains of *O. niloticus* and hybrids with *O. niloticus* as a parent, especially *O. niloticus* x *O. aureus* hybrids, are considered the fastest growers. Male *O. mossambicus* has much lower growth than other species.

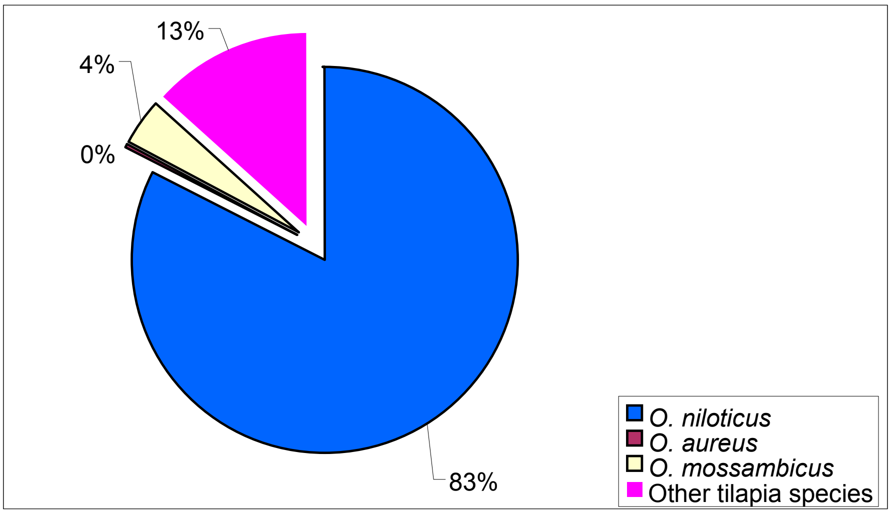
Oreochromis spp. hybridize readily in fishponds. Contamination with less desirable species, such as *O. mossambicus*, and years of inbreeding among pure strains can lead to slower growth (Popma and Lovshin 1996). The use of the recently developed improved tilapia strains (GIFT, GMT) represents a means by which the fish yields in ponds and other culture systems can be increased.

Global productions from aquaculture

The world's total tilapia aquaculture production in 2000 was 1.27 million mt and contributed about 3.6% of global total aquaculture production. The top five producing countries during 2000 are China, Egypt, Thailand, Philippines and Indonesia, each accounting for 49.7, 12.4, 7.8, 7.3 and 6.7%, respectively, of world's total aquaculture production of tilapia (FAO 2002).

Fig. 2 shows the tilapia aquaculture productions by major countries over the past 10 years. FAO (2002) statistics indicate that China has remained the number one producer both within Asia and globally; it produced 629 182 mt in 2000 which is more than 6 times the 1990 production. Egypt also made an impressive increase in tilapia production, from 24 916 mt in 1990 to 157 425 mt in 2000. On the other hand, production in Thailand only slightly increased while those in Philippines and Indonesia have almost remained stable during the period.

Fig. 1. Percent share of global tilapia aquaculture production according to species (Data source: FAO 2002)



In 2000, of the 1.27 million mt of tilapia produced from aquaculture, 85% was grown in freshwater environment, while 14.1% in brackishwater (FAO 2002).

Review on culture systems around the globe

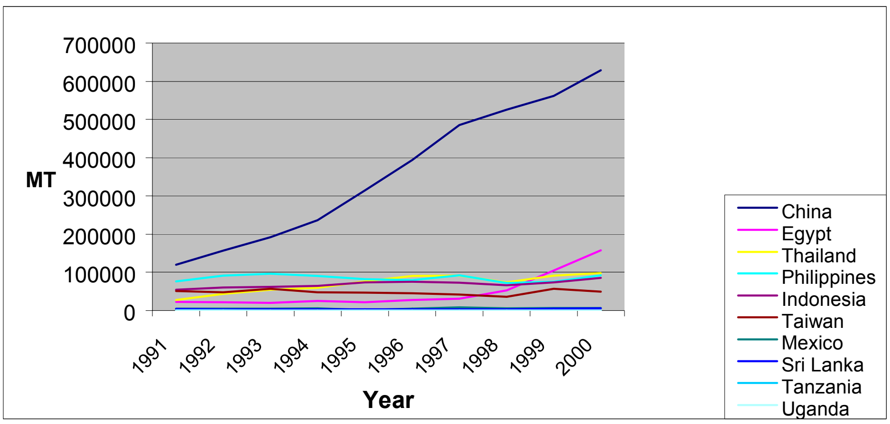
Tilapia farming ranges from a rural subsistence (extensive, low input practices, non-commercial and for household consumption) to a large-scale (capital intensive, commercial purpose and market driven) level, depending on the intensity of management employed. The following provide the details of the culture practices used globally.

Water-based systems

Cages

In Asia, the Philippines was the pioneer for cage culture in lakes and reservoirs in the region and practices semi-intensive and intensive farming (Guerrero 2002). It was reported that in 2000, the country's cages in 2000 ha of water produced a total of 33,067mt of *O. niloticus*. The average yield of 540 kg/ 100m^2 cage is attained with *O. niloticus* (mean weight of 175g each) after 5 months of rearing fingerlings. Unlike in Philippines where most cage farmers use Nile tilapia, farmers in China, Malaysia and Singapore prefer to grow Red tilapia hybrids in cages in former mining pools, rivers, irrigation canals and lakes/reservoirs using the semi-intensive and intensive method (Orachunwong et al 2001; Guerrero

Fig. 2. Tilapia aquaculture production by top ten producing countries (Data source: FAO 2002)



2001). In Indonesia and Thailand, cage culture of *O. niloticus* and Red tilapias in rivers, irrigation canals and lakes/ reservoirs and using the semi-intensive and intensive methods are practiced. Tilapia cage culture in Indonesia is mostly found in West Java, Jambi, South Sumatra and Kalimantan (Guerrero 2002).

Unlike in Asia, little information is available on cage culture in Africa. Jamu (2001) reported that cage culture systems which exist as pilot or fully operational especially in Southern and West Africa have not significantly contributed to actual tilapia production. However, a few have become successful in their cage culture operations and the largest is found in Northern Zimbabwe.

In America, Brazil dominates the tilapia cage culture industry and commercial cage culture operations are the major suppliers of the fish sold within and outside Brazil (Costa et. Al 2000). Five varieties of red tilapia are being cultivated with an annual estimated production of 80,000mt per year. Semi-intensive culture of Red tilapias in 6-18m^3 cages has allowed Brazilian producers to reach a productivity levels of 100 to 305 kg per m^3 per cycle (Alceste and Jory 2002, Costa et al 2000). Tilapia cage ranching in large lakes has also become prevalent in Mexico and Colombia where fisheries has been established in new reservoirs that were repeatedly stocked with tilapia fingerlings (Fitzsimmons 2000).

Land-based systems

Ponds

Most of the pond-based tilapia farmers in Bangladesh, China, Taiwan, Thailand and Vietnam use the polyculture system while in the Philippines, most farmers grow tilapias under the monoculture system. Culture methods followed in these countries vary depending on nature of farmland and farmers' capacity to invest. For example, in Bangladesh most farmers do not use commercial feeds and in Vietnam, farmers use only a small quantity of commercial feeds. On the other hand, in China, Taiwan, Thailand and the Philippines most farmers fertilize their ponds and feed the fish with formulated pellet feeds and use the semi-intensive to intensive systems.

In terms of pond yields, Dey (2001) reported that overall, the average yield of pond farming in Taiwan is very high (12 to 17mt/ha) while ponds in Bangladesh, China, the Philippines, Thailand and Vietnam produce around 1.7, 6.6., 3.0, 6.3 and 3.0mt/ha, respectively. Guerrero (2001) however claimed that in Philippines, the semi-intensive culture of *O. niloticus* in earthen ponds (0.25-1 ha, 1 meter depth) yields 4-8 mt (average size of 150-250g) per crop in 3-4 months with 80-90% survival.

Polyculture of tilapia with other native fishes in freshwater ponds is also widely integrated with agriculture and animal farming in Southeast Asia; particularly in Indonesia, Thailand, Vietnam, Cambodia and Myanmar. In Thailand, integrated livestock-fish systems have been the common practice in the Central region especially in relatively large farms since 1980s (Little 2000). About 60% of the total revenue from the integrated system is cash costs leaving 40% net income for the farmers. Similar success has been reported on polyculture of fish integrated with duck in Northeast Thailand. In Lao PDR, polyculture of *O. niloticus* in freshwater ponds is usually integrated with rice, vegetables or livestock while in Vietnam, tilapias are farmed mostly with pig or poultry.

In Israel, sex-reversed male *O. niloticus* and *O. aureus* hybrids are polycultured in earthen ponds with carp or monocultured in plastic-lined ponds at a high stocking density. Pelleted feeds and aeration are widely used and most tilapias produced are larger than 400g at harvest (Popma and Lovshin 1996). In Egypt, earthen pond aquaculture is the major type of culture system where only wastelands are allowed to be used for fish mainly because of their salt and alkali content and poor drainage. Semi-intensive aquaculture, which is done mostly in ponds, provides about 75% of the country's total aquaculture production (about 64,000 mt) and most farms are in northern or eastern part of Nile Delta (Alceste and Jory 2002).

In Africa, earthen ponds are the most important small-scale, monoculture at household level of tilapias, contributing about 38-93% of total tilapia production. Productivity varies from 0.5mt/ha/yr in extensive small-scale fishponds to 16 mt/ha/yr in commercial ponds (Jamu 2001). The species used is mostly *O. niloticus*. Apart from *O. niloticus*, other species such as *T. zillii* and *O. rendalli* are also cultured. Small-scale pond culture of tilapias are usually integrated with other agricultural enterprises such as vegetables, rice and other field crops. These systems produce twice as much income as non-integrated ponds and are reportedly more sustainable (Jamu 2001). Farming tilapias in ponds on a large scale on a semi-intensive basis also exist in some countries of Africa such as Zambia and Cote d'Ivoire.

Culture in freshwater ponds using the semi-intensive system is the practice of most commercial farmers in Brazil, Colombia, Costa Rica and Mexico. Polyculture of tilapias with shrimps is another trend in Latin America, especially in Ecuador and Peru where there were outbreaks of white spot disease in shrimps. Red tilapia hybrids which are known to be moderately (*O. niloticus* and *O. aureus*) to highly euryhaline (*O. mossambicus* and *O. hornorum*) are used for culture in brackishwater ponds traditionally used only for shrimp farming. With a crop rotation of shrimp and tilapias, tilapia production grew from 18 mt in 1990 to 15,000 mt in 2000 (Alceste et al 2001). It was reported that at an average salinity of 17ppt and a stocking density of 0.2fish/m^2, the farmers have increased the gross profitability of each production unit by over US$ 6.00 per day per hectare, in a 120 day-cycle (Fitzsimmons 2001; Alceste and Jory 2002).

Raceways and tanks

In Asia, intensive culture of tilapias in concrete tanks is practiced in Taiwan, Malaysia and Philippines. Taiwan is the pioneer in the region for the intensive culture of tilapia in concrete tanks and produces over 50,000 tons annually, most operations being small to medium level operations (Liao and Chin-Wei 2001). Red tilapias are cultured in 100-m^2 octagonal tanks with water change and aeration, and with fish weighing 100-200g and densities of 50-100/m^2.

With 3-4 times of feeding per day using commercial feeds and automatic feeders, yields of 3-4mt/tank/cycle of 3-4 months are obtained with fish weighing 600g on the average, survival of 90% or higher and feed conversions of 1.2-1.4 (Guerrero 2002). Although raceways/tank culture of tilapias is not a common practice in Africa, it is also used in some areas.

Intensive culture in raceways and round tanks with recirculating systems inside green houses or insulated buildings in order to maintain warmth has been developed in the US, Canada, Brazil and Mexico. Mexico is the biggest producer of tilapia in the Western Hemisphere (6,726 mt in 2000) and with the highly developed internal market, culture methods have become more intensive using raceway and improved technologies (Fitzsimmons, 2001). In Canada and the United States, the rearing of tilapias in raceways using aquaponics system has been shown to be technically feasible and economically possible where fresh fish and vegetables receive a premium price (Fitzsimmons 2000).

Comparative assessment of culture systems and management strategies

Culture systems

The choice of the culture system is mainly influenced by the objective of the farmer or as determined by the circumstances/conditions which include culture sites, infrastructure, environmental conditions (especially climate), socio-economic factors, technological know-how and marketing potential.

Among the culture systems, earthen pond is the most versatile for extensive, semi-intensive and intensive tilapia production. Use of earthen ponds is economically viable only when warm year-round climate, suitable land and relatively large quantities of water are available. The major drawback of pond culture is the greater risk of uncontrolled reproduction if certain measures are not taken to minimize this possibility.

Cage culture of tilapias is practiced in countries where lakes, large reservoirs, rivers, estuaries are available. Compared to ponds and raceways, the use of cages require relatively low capital investment and offers flexibility of management. Another advantage is that breeding cycle of tilapia is disrupted in cages, and therefore mixed sex population can be reared without the problems of recruitment and stunting, which are major constraints in pond culture.

Tanks and raceways can only be a good alternative to pond or cage culture if sufficient water or land is not available and economics are favorable. Unlike ponds, it is easier to manage the stocks and exert a relatively high degree of environmental control over water quality parameters. However, tank and raceway culture requires higher investment due to increased construction and production costs (complete commercial diet, aeration, recirculating system). The farming of tilapias in tanks/raceways also needs close and constant attention due to higher risk of major fish mortality caused by disease outbreak and mechanical or electrical failure.

Economics of commercial production

Overall, tilapia farming is profitable but the costs of production and profits vary considerably across countries, production environments and culture systems. Dey and Paraguas (2001) reported that cage operations in Indonesia cost an average US$ 0.43 to produce 1 kilogram of tilapia while in China, the average cost is higher (US$ 1.30). In the case of ponds, farmers in the Philippines spend an average US$0.99 to produce one kilogram of tilapia while farmers in Bangladesh spend only an average of US$ 0.16. In these culture systems, feed accounts for most of the total production costs ranging from 34% (ponds) to 87% (cages). Although production costs may vary from country to country depending on the level of management used, tilapia cage culture requires much lower capital investment and operating cost than in pond and tank culture or raceway (Orachunwong et al 2001). Among the culture systems, the cost of growing tilapias in tanks and raceways is highest. Published estimates in growing tilapias in tanks/raceways with intensive flow-through system range from US$ 2.12 to US$ 2.80/kg (Hargreaves and Behrends 1997).

Irz (2002) compared the profitability and technical efficiency of intensive monoculture of tilapia in freshwater ponds and the extensive polyculture of prawns, tilapia and milkfish in brackish water ponds in the Philippines. He found that both production systems are lucrative, with brackish water polyculture achieving the higher level of profit per farm. With a production cost of P417,075/ha (Philippine Peso 53 = 1 US dollar) the freshwater monoculture of tilapia obtained a net income of P226,778/ha or a profit margin of 35%. On the other hand, the production cost of the extensive polyculture of tilapia in brackish water was P71,246/ha produced a net income of P51,361/ha or a profit margin of 42%. In China, where both monoculture and polyculture are practiced in ponds, the latter was also found more productive than the former both in terms of production value and quantity (Dey and Paraguas 2001). Similarly in Panama, it was found that polyculture was more profitable than monoculture systems for commercial production targeting domestic market. Net returns to monoculture of tilapia were US$ 645/ha and net returns to polyculture of tilapia, grass carp and freshwater prawns were US$ 3,291/ha (Engle 1997).

In Puerto Rico, the imported feed, processing and distribution and sex-reversed fry were the greatest operating cost in commercial salt-water pond culture systems. The breakeven price was US$ 3.86/kg and the system generated internal rate of return of 18% (Watanabe et al 1997).

Constraints to tilapia farming

The shortage of fry production is still one of the factors limiting the expansion of tilapia culture. Poor broodstock productivity owing to low fecundity and asynchronous spawning cycles, remains one of the most significant outstanding constraints to commercial tilapia production and its future expansion.

Deterioration in genetic quality has come to be a major constraint in tilapia farming, even among small-scale producers. For example, in sewage-fed farms near Hanoi, Vietnam low value tilapias were produced before the recent introduction of new strains. The characteristics of 'improved' tilapia seed have generally been related to faster, more efficient production, better appearance, tolerance to certain environmental conditions, and especially, control of breeding.

Substantial benefits in terms of growth rates and improved yields under culture have been demonstrated from breeding programs for selection and sex control. The results of the successful application of these breeding programs need to be introduced to aquaculture through technically and economically sustainable dissemination programs (Mair 2002).

The lack of attention given to marketing and other business aspects has also been identified as one of the constraints to success of commercial tilapia farming. Market evaluations are seldom undertaken by aquaculturists because of time and expense and difficulties in obtaining the cooperation of wholesalers and retailers (Watanabe et al 1997). They claimed that a culture bias against freshwater fish and against fish with a silver-black appearance of most common varieties of tilapias (primarily *O. mossambicus*) has limited the market demand and commercial production of tilapias in many areas.

Conclusion

A few years ago, a greater part of tilapia production was consumed locally, with Africa and Asia as traditional countries. In recent years however, there has been a growing acceptance and consumption of tilapias in non-traditional countries such as USA, Canada, Europe, Central and South America. In US alone it was reported that importation increased to about 75,000mt (whole fish equivalent), supplying nearly 90% of the country's demand. In view of the escalating demand of this commodity, tilapia farming will continue to be an important source of animal protein, foreign exchange and employment opportunities in several countries.

Ferdouse (2001) indicated that whether the tilapias that are being produced are for export or for domestic consumption, the quality of the fish and convenience are important factors that will influence the consumer demand, particularly in urban market in Southeast Asia. She claimed that in the affluent urban markets in this region (Hong Kong, Malaysia, Singapore and Thailand), good quality fish (without any foul or muddy odour) and convenience food (e.g. fish prepared into skinless fillets) will continue to help in tilapia sales for household consumption through retail outlets such as supermarkets.

References

Alceste-Oliviero, C. 2000. Regional review of aquaculture status and development trends in the Latin America and Caribbean. Book of Synopses. NACA and FAO International Conference on Aquaculture in the Third Millenium, 20-25 February 2000, Bangkok, Thailand.

Alceste, C.C., J.A. Illingworth and D.E, Jory. 2001. Tilapia farming industry in Ecuador. Aquaculture Magazine. 27(3):77-82. May-June 2001.

Alceste, C.C. and D.E. Jory. 2002. World tilapia farming. Available at: http://www.aquaculturemag./com/siteenglish/printed/buyers/web.tilapia.html

Anon. 1984. Introducing the tilapias. ICLARM Newsletter. January 1984. 7(1):3.

Anon. 2000. Peru: disease-hit farms turn to tilapia. INFOFISH International. 3/2000. May/June issue.

Baroiller, J.F. 1996. Significant proportions of unexpected males in progenies from single pair matings with sibling sex reversed males of *Oreochromis niloticus*, p. 229-237. In R.S.V. Pullin, J. Lazard, M. Legendre, J.B. Kothias and D. pauly (eds.). The Third International Symposium on Tilapia in Aquaculture. ICLARM Conf. Proc. 41, 575p.

Blow, P. 2001. Handling and processing for export. p. 123-127. In Subasinghe, S. and S. Tarlochan. 2001. Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Chapman, F.A. 2003. Culture of hybrid tilapia: A reference profile. Available at: http://edis.ifas.ufl.edu/body_FAO12.

Costa, F.H.., Sampajo, A.H., Saker-Sampajo, S., Lima, F.M, Matias, J.F.N., Rocha, I.R.C.B, Santos, J.A.R. and Rochas, P.J.C. 2000. In K. Fitzsimmons and J.C. Filho. Tilapia cage culture in reservoir in Cear State, Brazil. Tilapia Aquaculture in the 21st Century. Proceedings from the Fifth International Symposium on Tilapia Aquaculture, 3-7 September 2000, Brazil. Vol.2.

Dey, M. 2001. Tilapia production in South Asia and the Far East. p. 17-27. In Subasinghe, S. and S. Tarlochan. 2001. Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia

Dey, M.M. and F.J. Paraguas. 2001. Economics of tilapia farming in Asia. p. 33-46. In Subasinghe, S. and S. Tarlochan. 2001. Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001. International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Dey, M.M, A.E. Eknath, Li Sifa, M.G. Hussain, T.M. Tran, V.H. Nguyen, S. Aypa and N. Pongthana. 2000a. Performance and nature of genetically improved farmed tilapias: a bio-economic analysis. Aquaculture Economics and Management. 4(1/2):83-106.

Eknath, A.E. and B.O. Acosta. 1998. Genetic improvement of farmed tilapia project final report (1988-1997). ICLARM, Manila, Philippines. 75pp.

Engle. C. 1997. Economics of tilapia aquaculture. p. 229-243. In B.A. Costa-Pierce and J.E. Rakocy, eds. Tilapia Aquaculture in the Americas. Vol. 1. World Aquaculture Society, Baton Rouge, Lousiana, United States.

FAO. 2002. Fishery Statistics. Aquaculture production. 90(2).

Ferdouse, F. 2001. Tilapia in Asian markets… can we sell more?.p. 71-71. In Subasinghe, S. and S. Tarlochan (eds.). Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Fitzsimmons, K. 2000. Tilapia: the most important aquaculture species in the 21st century. In Fitzsimmons, K. and J.C. Filho (eds.) Tilapia Aquaculture in the 21st century. Proceedings from the Fifth International Symposium on Tilapia Aquaculture. Rio de Janeiro, Brazil. Vol. 1.

Fitzsimmons, K. 2001. Tilapia production in the Americas. p. 7-16. In Subasinghe, S. and S. Tarlochan (eds.). Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Guerrero, R.D. III. 2001. Tilapia culture in Southeast Asia. p. 97-103. In Subasinghe, S. and S. Tarlochan (eds.). Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Guerrero, R.D. 2002. Tilapia farming in the Asia-Pacific Region. p. 42-49. In Guerrero, R.D. III and M.R. Guerrero del-Castillo (eds.). Tilapia Farming in the 21st century. Proceedings of the International Forum on Tilapia Framing in the 21st Century (Tilapia Forum 2002), Laguna, Philippines.

Hargreaves, J.A. and L.L. Behrends. 1997. Improving the economics of intensive tilapia aquaculture in the Southeastern United States through integration: a conceptual assessment. p. 642-649. In: Fitzsimmons, K (ed.). Tilapia Aquaculture – Proceedings from the Fourth International Symposium on Tilapia in Aquaculture. Florida, USA, 9-12 November 1997. Vol. 2.

Irz, X. 2002. Profitability and technical efficiency of aquaculture: a comparison of intensive and extensive production systems in the Philippines. p. 87-99. In Guerrero, R.D. and M.R. Guerrero del-Castillo. Tilapia Farming in the 21st Century.

Jamu, D. Tilapia culture in Africa: Opportunities and challenges. 2001. p. 105-112. In Subasinghe, S. and S. Tarlochan. Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Lazard, J.P. 1996. Which research for development of tilapia aquaculture in subSaharan Africa? p. 515-524. In: R.S.V. Pullin, J. Lazard, M. Legendre, J.B. Amon Kothias and D. Pauly (eds.). The Third International Symposium on Tilapia in Aquaculture. ICLARM Conf. Proc. 41, 575p.

Liao, D.S. and Chin-Wei Chen. 2001. Socio-economics and technical efficiency of tilapia production in Taiwan. 6th Asian Fisheries Forum Book of Abstracts, p. 147.

Little, D. 2000. Meeting the needs of the poor in Asia-tilapia in the new millennium. p.641-650. In: K. Fitzsimmon and J.C. Filho (eds.). Proceedings from the Fifth International Symposium on Tilapia Aquaculture, Rio de Janeiro, Brazil, 3-7 September 2000.

Mair, G. 2001. Genetics in tilapia aquaculture. Tilapia production in the Americas. p. 136-148. In: Subasinghe, S. and S. Tarlochan (eds.). Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Continued on page 16

most famous being in the town of Xochimilco, south of Mexico City. Xochimilco is a tourist area with brightly painted flat-bottomed boats plying the canals propelled by boatmen using long poles, some with mariachi bands to entertain the tourists. Most of the produce is now flowers and ornamental plants for the markets of Mexico City.

The chinampas were reclaimed from the marshy shallows along the shores of lakes and around the island city of Tenochtitan. Long and narrow rectangular enclosures were staked out in the swampy lakebed. The stakes were joined with fences of woven branches and filled with mud and decaying vegetation with narrow canals left in between. Tall slender willow trees were planted around the perimeter, which developed a dense root system that anchored the retaining walls. As well as being fertilized periodically with mud scooped up from the bottom of the canals, which was spread on the plot before planting a new crop, the Aztecs used nightsoil transported from the city in canoes.

Fish abounded in the canals as recently as 40 years ago (Coe, M.D. 1964. The chinampas of Mexico. Scientific American 211:90-98) and were netted or speared by the chinamperos, the chinampa farmers. The axolotl, a large aquatic salamander was also prized for its tender meat. It is known that the Aztecs caught fish with bag shaped nets woven from cactus fibre and also with hooks, lines and harpoons. There does not appear to be documentary evidence for the Aztecs farming fish but the ruling class had pleasure gardens with ponds containing fish.

Chaya leaves being consumed by tilapia.

Transporting ornamental plants along a chinampa canal in Xochimilco.

Continued from page 12

Mair, G. 2002. Tilapia genetics and breeding in Asia. p. 100-123. In: Guerrero, R.D. III and M.R. Guerrero-del Castillo (eds.). Proceedings of the International Forum on Tilapia Farming in the 21st Century (Tilapia Forum 2002), 184p. Philippine Fisheries Association Inc. Los, Banos, Laguna, Philippines.

Mair, G.C., J.S. Abucay, D.O.F. Skibinski, T.A. Abella and J.A. Beardmore. 1997. Genetic manipulation of sex ratio for the large-scale production of all-male tilapia, Oreochromis niloticus. Canadian Journal of Fisheries and Aquatic Science, 54: 396-404.

Orachunwong, C., S. Thammasart, and C. Lohawatanakul. 2001. Recent developments in tilapia feeds. p. 113-122. In Subasinghe, S. and S. Tarlochan. 2001. Tilapia: production, marketing and technological developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia, 28-30 May 2001, Kuala Lumpur, Malaysia.

Popma, T.J. and L.L. Lovshin. 1996. Worldwide prospects for commercial production. Research and Development Series No. 41. Department of Fisheries and Allied Aquaculture, Auburn University, Alabama, USA. 23p.

Pullin, R.S.V. 1983. Choice of tilapia species for aquaculture. p. 64-76. In: L. Fishelson and Z. Yaron (eds.). International Symposium on Tilapia in Aquaculture. Tel Aviv University, Israel.

Shelton, W.L. 2002. Tilapia culture in the 21st century. p.1-20. In: Guerrero, R.D. III and M.R. Guerrero-del Castillo (eds.). Proceedings of the International Forum on Tilapia Farming in the 21st Century (Tilapia Forum 2002), 184p. Philippine Fisheries Association Inc. Los, Banos, Laguna, Philippines.

Watanabe, W.O., B.L. Olla, R.L. Wicklund and W.D. Head. 1997. Saltwater culture of Florida red tilapia and other saline-tolerant tilapias: a review. p. 54-141. In: B.A. Costa-Pierce and J.E. Rakocy (eds.) Tilapia in the Americas, Vol. 1. World Aquaculture Society, Baton Rouge, Lousiana, United States.

Commission Working Party of Experts on Inland Fisheries, Bogor, Indonesia, 24-29 June 1991. FAO Fisheries Report No. 458 Supplement

Yap, S.Y. 2002. Fish production in integrated farming systems. Available at: http://www.fao.org/docrep/004/ac155e13htm

Zohar, G. and U. Rappaport. 1985. Intensive culture of tilapia in concrete tanks. Bamidgeh. 37(4).