

Tilapia farming: A global review

Inland aquaculture

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A REVIEW OF GLOBAL TILAPIA FARMING PRACTICES

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ABSTRACT

Tilapias are an important component of subsistence fisheries for thousand of years but have gained prominence in recent years in areas where they are not endemic. Introductions of better performing tilapia species/strains and development of techniques to manage unwanted reproduction have spurred significant developments that led to success in tilapia farming.



Of the 70 species of tilapias, 9 are used in farming and of these, Nile tilapia (*Oreochromis niloticus*) is the main cultured species and responsible for the significant increase in global tilapia aquaculture production. Tilapia contributed 1.27 million metric tons in 2000 or 3.57% of global aquaculture production. The major producing countries are China, Egypt, Thailand, Philippines and Indonesia.

Tilapia farming ranges from rural subsistence farming to large-scale commercial operations depending on intensity of management employed. Earthen ponds are the most common culture system worldwide. Concrete tanks and raceways are commonly used in countries where temperature is seasonal and mainly for intensive and super intensive culture of tilapias. Cage culture is mainly practiced in lakes, reservoirs, rivers and estuaries.

The use of different culture systems (earthen pond, concrete tank, raceway, cage) and management strategy (extensive, semi-intensive, intensive, monoculture, polyculture, monosex culture, mixed sex culture) depends on farmer's resources, site characteristics, environmental conditions, socio-economic factors, technological know-how and market demand. Production costs and yields vary from country to country depending on the level of management used.

The expansion of tilapia farming is constrained by a number of factors, which include among others, shortage of fry and deterioration in genetic quality. Improved breeds of tilapias from breeding programs on selection and sex control have been developed but there is a need for sustained

production and effective dissemination of these to farmers. The lack of attention given to marketing and other business aspects is also a constraint to successful commercial farming of tilapias.

INTRODUCTION

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 4000 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 be 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 solutions 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 limitation 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 3 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. 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. 1 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.

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 is the pioneer for cage culture in lakes and reservoirs in the region and practices the 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/100m² 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 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 6-18m³ cages has allowed Brazilian producers to reach a productivity levels of 100 to 305 kg per m³ 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 majority of farmers do not use commercial feeds and in Vietnam, farmers use only small quantity of commercial feeds. On the other hand, in China, Taiwan, Thailand and the Philippines majority of farmers fertilize their ponds and feed the fish with formulated pellet feeds and use the semi-intensive to intensive system.

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 system has 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 waste lands 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/m², the farmers have increased the gross profitability of each production unit by over US\$ 6.00 per day per hectare, in 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-m² octagonal tanks with water change and aeration, and with fish weighing 100-200g and densities of 50-100/m². 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 in 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 costs 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 brackishwater ponds in the Philippines. He found that both production systems are lucrative, with brackishwater polyculture achieving the higher level of profit per farm. With a production cost of P417,075a/ha 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 brackishwater was P71246/ha produced a net income of P51361/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, 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

Only 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.

Whether for export or the local market, consumers especially those from urban areas will buy because of quality and convenience, according Fatima Ferdouse of INFOFISH (2001). She reported that in the affluent urban markets in this region (Hong Kong, Malaysia, Singapore and Thailand), good quality fish (without foul odor or muddy taste) and convenience food (e.g. fish prepared into skinless fillets) will continue to help sell tilapia through retail outlets such as supermarkets.

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

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

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