Evaluation of Production Characteristics of Four Strains of Nile Tilapia *Oreochromis niloticus* and a Red Variety Under Two Sets of Intensive Culture Conditions

by

Mark Alan Peterman

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 12, 2011

Approved by

Ronald Phelps, Chair, Associate Professor of Fisheries and Allied Aquacultures
Jesse Chappell, Associate Professor of Fisheries and Allied Aquacultures
William Daniels, Professor of Fisheries and Allied Aquacultures
Randell Goodman, Director E.W. Shell Fisheries Center

Abstract

The wide native range of Nile tilapia *O. niloticus* offers the possibility of genetic diversity within the species and variation among populations as to their suitability for aquaculture. But only a few populations have been evaluated as to their aquaculture potential and less in head to head comparisons. A series of trials were conducted at Auburn University to compare production characteristics of four populations of *O. niloticus* using two domesticated strains (Egypt and Ivory Coast) and two less domesticated strains (Sagana and Lake Victoria). In addition, a red variety of tilapia (Santa Fe) was also evaluated.

In the first trial, the different strains were compared under high density conditions in an indoor recirculating system at a mean (±SD) temperature of 27.1 ± 2.8 ^{o}C and fed commercially available diets. Initial mean (±SD) standing crop (kg/m^3) ranged from 2.1 ± 0.1 (Sagana) to 2.7 ± 0.1 (Egypt) for a 203 day culture period. No one strain showed a distinct production advantage during this period. Mean (±SD) percent (%) survival ranged from 81.7 ± 6.8 % for the Ivory coast line to 97.5 ± 5.5 % for the Egypt line. Mean (±SD) feed conversion ratios during this period ranged from 1.4 (± 0.1) to 1.6 (± 0.1).

A second study compared the growth of manually-sexed males from the five tilapia strains in aerated 20 m^2 outdoor static water tanks. Fish with an initial mean (±SD) weight (g) range from 94 ± 5.4 (Red) to 108 ± 6.9 (Egypt) were stocked on May 30, 2007 at 2 fish/m^2 and fed twice daily to satiation a 36% protein floating commercial feed. After a 120-day culture period, yield, survival and feed conversion ratio were compared. There were no production

differences among all Nile strains. Nile strains out-performed the Red variety in several traits. Mean (±SD) standing crop (kg/ha) at harvest was less for the Red strain and ranged from 9,508 ± 396 (Red) to 14,438 ± 779 (Sagana). There was a significant difference (P = 0.01) in mean (±SD) male average weight (g) of the two smaller strains of Lake Victoria (365 ± 37) and Ivory Coast (380 ± 20) when compared to the larger Sagana 473 ± 30. Mean (±SD) % survival ranged from 78.8 ± 13.9 (Red) to 98.3 ± 1.7 (Egypt). Mean (±SD) feed conversion ratios were 1.3 ± 0.2 (Ivory Coast), 1.3 ± 0.1 (Sagana) to 1.9 ± 0.1 (Red).

A third study compared fish processing characteristics of the five tilapia strains. The fish (n = 25 per strain) were harvested, stored on ice (2 ± 0.25 hrs) and manually processed into fillets. Mean percent fillet dress-out and mean percent visceral fat were compared. The Ivory Coast had highest mean (±SD) % fillet dress-out (33.1 ± 2.1) and the Sagana had the lowest (29.6 ± 1.5). The Red variety had the highest mean (±) % visceral fat (2.3 ± 1.0) and the Sagana had the lowest (0.2 ± 0.4).

Acknowledgements

The author would like to thank Beth, J.J., and Riley Peterman for their support, patience and understanding during the course of this program. Special thanks to Ronald P. Phelps for his guidance and expertise. In addition, the project would have not been accomplished without funding from the Alabama Experiment Station and support from the staff of the E.W. Shell Fisheries Center, Auburn, AL.

Table of Contents

List of Tables

List of Figures

Chapter 2

CHAPTER 1

LITERATURE REVIEW

History

The farming of tilapia is believed to have originated more than 4,000 years ago from Egypt (Hickling, 1963; Gupta and Acosta, 2004). The first recorded scientifically oriented culture of tilapia was conducted in Kenya in 1924 (Maar et al., 1966) and soon spread throughout Africa. Tilapia was later transplanted and became established as a potential farmed species by the mid 1950's in the Far East (Xia, 2000) and in the Americas (Watanabe et al., 2002). There exists an extensive bibliography on all aspects of its biology and culture (Chimits, 1955; Thys van den Audenaerde, 1968; Schoenen, 1982; World Fish Center, 2003).

The majority production of Nile tilapia (*Oreochromis niloticus*) is based on six initial sources: Ivory Coast, Ghana, Egypt-Manzala, Egypt-Ismailia, Sudan-Nile and Lake George Uganda. These founding stocks were commonly established from a limited number of wild fish. Most of these introductions were made in the late 1960's and early 1970's and have been redistributed throughout the world (Khater and Smitherman, 1988; Pullin and Capili, 1988). This, along with the high fecundity rates of tilapia, has resulted in a high incidence of inbred stocks. These stocks have retained their wild color patterns.

O. niloticus from different geographical regions have similar coloration (Mires, 1988). Their dorsal region is black, the middle section is olive and the ventral, silvery white. Red coloration mainly around the head can be seen under the black pigmentation. These red areas

become brighter during breeding season, especially in males. Wild type *O. niloticus* typically have vertical stripes on the tail and dorsal fin.

The genetic heritage of red tilapia is generally attributed to the crossbreeding of mutant reddish-orange *O. mossambicus* (a normally black/grey species) with other species, including *O. aureus*, *O. niloticus*, and *O. hornorum* (Fitzgerald, 1979; Behrends et al., 1982; Galman and Avtalion, 1983; Kuo, 1984). These stocks have retained their wild color pattern. The red coloration in tilapia was first produced in Taiwan in the late 1960's from a cross between a mutant reddish-orange female *O. mossambicus* and a normal male *O. niloticus* (Popma and Masser, 1999). It was called the Taiwanese red tilapia. Another red strain of tilapia was developed in Florida in the 1970's by crossing a normal colored female *O. hornorum* with a red-gold *O. mossambicus* (Popma and Masser, 1999). A third strain of red tilapia was developed in Israel from a mutant pink Nile tilapia crossed with wild Blue tilapia (*O. aureus*) (Popma and Masser, 1999). All three original strains have been crossed with other red tilapia of unreported origin or with wild *Oreochromis* species. Consequently, most red tilapias in the Americas are mosaics of uncertain origin. The confused and rapidly changing genetic composition of red tilapia, as well as the lack of "head-to-head" growth comparisons between the different lines, makes it difficult for a producer to identify a "best" red strain.

Market

Tilapia farming has grown from efforts around the world by development agencies to feed the rural poor now to highly domesticated livestock production with global sales now exceeding $ 2 billion (U.S.) a year (Fitzsimmons, 2006). Tilapia, because of their enormous adaptability and ability to reproduce under a wide range of physical and environmental

conditions, excellent growth rates on a wide variety of natural and prepared diets, resistance to handling and disease-causing agents, and broad consumer appeal as a food fish, are the most successfully cultured fish species worldwide (Lim and Webster, 2006). Furthermore, the Nile tilapia rose rapidly to the greatest international prominence among tilapia in the latter part of the 1990's, accounting for more than 60 % of world tilapia production, largely because of its fast growth rate, adaptability to various culture conditions, and consumer acceptance (Macintosh and Little, 1995; Shelton, 2002).

Currently, the United States is the third largest seafood importer following the European Union and Japan (USDA FAS, 2005). The United States (U.S.) currently imports 84% of the seafood products consumed (2.3 million metric tons) and 50% of that is from aquaculture (USDOC, 2010). The U.S. imports of tilapia (measured in million $ U.S.) primarily from the countries of Indonesia (68), Honduras (57), China (55), Ecuador (54), Taiwan (37), Columbia (14) and Costa Rica (12) (U.S.D.O.C., 2010). It is estimated that by 2020 the top four seafood products consumed will be shrimp, salmon, tilapia and catfish (USDA FAS, 2005). The total U. S. aquaculture production in 2008 was valued at $1 billion (U.S.), compared to world aquaculture production valued at $70 billion (U.S.) (USDOC, 2010). Eighty-five percent of the U.S. aquacultured tilapia is sold live and 15% is processed into products, such as whole fish, de-headed and gutted whole fish, and fillets (Fernandes 2000).

Taxonomy

Tilapias are endemic to tropical freshwater in Africa, Jordan and Israel, where more than 70 species have been identified (Philippart and Ruwet, 1982; Macintosh and Little, 1995; McAndrew, 2000). Trewavas (1982, 1983) divided commercially important tilapia into three

taxonomic groups, based on reproductive characteristics. *Tilapia spp.* guard the developing eggs and fry in the nests. *Oreochromis spp.* females incubate eggs and fry orally. *Sarotherodon spp.* males and/or females incubate eggs and fry orally. Relatively few of the 70 species are commercially important, and even fewer are of aquacultural significance (Shelton and Popma, 2006). Popma and Lovshin (1996) listed the common and scientific names of commercially important cultured species.

Nile tilapia *Oreochromis niloticus*	Zanzibar tilapia *Oreochromis urolepis hornorum*
"Red" tilapia *Oreochromis spp.*	"White" or "pearl" tilapia *Oreochromis spp.*
Blue tilapia *Oreochromis aureus*	Galilee tilapia *Sarotherodon galilaeus*
Java tilapia *Oreochromis mossambicus*	Black-chinned tilapia *Sarotherodon melanotheron*
Mossambique tilapia (*Oreochromis mossambicus*)	Congo tilapia *Tilapia rendalli*

Oreochromis niloticus has been subjected to detailed morphological study and analysis. The most recent systemic treatment (Trewavas, 1983) divided the taxon into seven subspecies: *O. niloticus baringoensis* (Trewavas), *cancellatus* (Nichols), *eduardianus* (Boulenger), *filoa* (Trewavas), *niloticus* (Linnaeus), *sugutae* (Trewavas) and *vulcani* (Trewavas). This classification is based on osteological features and composite differences in meristic and morphometric characters. However, none of theses characters, either singly or in combination, can be used to unambiguously identify individual fish: all characters overlap among subspecies (Seyoum and Kornfield, 1992a). Because all subspecies of *O. niloticus* can be distinguished by their unique restriction enzyme profiles, analysis of mitochondrial DNA can be used to identify the origin of cultured stocks (Seyoum and Kornfield, 1992). Utilizing this technology Seyoum and Kornfield (1992b) described an eighth subspecies: *Oreochromis niloticus tana*.

Genetics

A challenge when establishing new fish species for use in aquaculture is to begin with adequate genetic diversity. The genetics of cultured tilapia have routinely been poorly managed (Kocher, 1997). Much of tilapia culture outside its native range has been based on a limited number of introductions from a small number of individuals. This has given rise to at least three forms of genetic concerns (Kocher et al., 1998). First is the loss of pure species through mismanagement of inter-specific hybridization (McAndrew, 1993), a technique used to produce all-male fry which have a higher growth rate in production systems (Hickling, 1960; Hulata et al., 1983). One popular commercial strain of red color variant is thought to contain genes from as many as four species (mentioned in reference: *O. niloticus, O. mossambicus, O. hornorum*) (McAndrew et al., 1988). A second problem is high levels of inbreeding depression. During domestication, unintentional selection of traits that increase survival and reproductive success can be negatively correlated with growth, seinability, dress-out or other commercially important characteristics (Doyle, 1983; Tave, 1986). Furthermore, domestication selection pressures may produce a genotype-environmental effect. This is where species are selected for production traits that have evolved under a specific set of culture conditions (e.g. temperature, water quality, quality of nutrient inputs, etc). Therefore, fish that perform well under one set of culture conditions may not be well-suited to another. Finally, there is evidence for contamination of genetically improved strains by introgression from feral species (Macaranas et al., 1986).

Since aquaculture species represent isolated breeding populations with distinct genetic attributes, the first step of selection is to characterize available strains or lines and subsequently select one or more that excel in certain areas from which to form a base population for improvement. This is of particular significance in tilapia due to the frequent use of small

founder populations and accelerated inbreeding among isolated production stocks (Lutz, 2006). Temperature, salinity, fecundity, feeding habits and growth have all been evaluated under a variety of conditions, but results have often been somewhat variable among studies evaluating the same species (Lowe, 1955; Maar et al., 1966; Yashouc and Helevy, 1971; Fryer and Iles, 1972; Jhingran and Gopalakrishnan, 1974; Wohlfarth and Hulata, 1981). Such variability may be explained in part by differences among particular strains within species, and this phenomenon certainly appears to exist in tilapia (Eknath et al., 1993).

Variation in genes is essential for organisms to adapt to ever-changing environments. A diploid organism is heterozygous at a gene locus when its cells contain two different alleles of a gene. Since a population needs variation, the amount of heterozygous genes "heterozygosity" can be used as a general indicator of the amount of genetic variability and genetic health of a population. Heterozygosity is important to the well-being of natural and artificial (cultured) populations for two reasons (Beardmore et al., 1997). First it allows, through the normal processes of recombination and segregation, the production of a range of genotypes that can exploit the available resources in subtly different ways and which are available as a spectrum of different types which can be drawn upon for adaptive response to changed conditions. Secondly, there is evidence that indicates that more heterozygous individuals are superior to less heterozygous individuals in characteristics like growth in the blue mussel (*Mytilus edulis*) (Gentili and Beaumont, 1988; Zouros and Pogson, 1994), fertility in brine shrimp (*Artemia franciscana*) (Gajaro and Beardmore, 1989), survival in the guppy (*Poecilia reticulata*) (Beardmore and Shami, 1989) and size in the rainbow trout (*Oncorhynchus mykiss*) (Danzmann et al., 1988).

There is research that suggests that genetic development can lead to improved tilapia growth and survival (Bestari, 2004). Smitherman and Tave (1987) reported that maintenance of an effective breeding number of 100-150 broodfish sustains 99% of genetic variability and reduces inbreeding depression. The experience of selective breeding in tilapias has been reviewed by Penman and McAndrew (2000) who concluded that the low heritability for growth observed in many trials were an outcome of the low genetic variation typical of the cultured stocks used. The genetically improved farmed tilapia (GIFT) program based on a synthetic base population from wild and domestic stocks of Nile tilapia resulted in improved growth and survival (Longalong et al., 1999; Khaw et. al., 2008; Ridha, 2006). The program aimed to produce high performing base stocks that could be further selected by national centers in countries wishing to improve tilapia culture. The benefits to farmers from the program, which is ongoing, varied by country; in Bangladesh GIFT compared very favorably to many local strains (Mazid et al, 1996) but differences were much less evident in Vietnam and Thailand where local strains performed well (e.g. Dan and Little, 2000). In addition, there was evidence that the GIFT strains were less tolerant to cooler climates (Li et. al., 2002).

Strain comparison is a complex topic considering the issues of fish size, age, genotype-environment interactions and various domestication selection pressures. Uraiwan (1988) confirmed that a genetic relationship exists between growth rate, age and size at sexual maturity in Nile tilapia. In this study, lines that were selected for early sexual maturation were larger and grew faster than lines that took longer to become sexually mature. Romana-Eguia and Doyle (1992) observed a significant genotype-environmental interaction in the response of three *O. niloticus* strains to poor nutrition. Li et al. (2002) reported difference among Nile strains of

tilapia relative to cold tolerance. Macaranas and Fujio (1990) reported on genetic changes in broodstocks of five cultured fish species (*Salvelinus alpinus, O. niloticus, O. mossambicus, Cyprinus carpio and Poecilia reticulata)* and showed them to be influenced by the intensity of selection pressure and/or history of culture. Osure and Phelps (2006) reported differences in relative fecundity (seed/g female), percent females that spawned and incubation success among four strains of Nile tilapia with varying degrees of domestication.

Water Quality

The general influence of temperature on tilapia is summarized by Balarin and Haller (1982), Chervinski (1982), Philippart and Ruwet (1982), and Wohlfarth and Hulata (1983). Optimal growth temperatures should range from 30-32^{o}C (Popma and Masser, 1999). Tilapia exhibit three times more growth at 30-32^{o}C than at 22^{o}C. They become stressed at temperatures lower than 18 ^{o}C. Thermal responses include decreased to complete stoppage of feeding and decreased tolerance to other stressors. Temperatures less than 10 ^{o}C are lethal. Tilapias often tolerate a wide range of salinities (Stickney, 1986b; Suresh and Lin, 1992a). Nile tilapias are among the least tolerant to high salinity and typically tolerate up to 15 g/L (Popma and Masser, 1999). Mozambique tilapia is one of the most saline tolerant; it can survive salinities to 75 g/L, grows well and reproduces at salinities up to 50 g/L and grows optimally in brackish water (Balarin and Haller, 1982). Red tilapia can be cultured in freshwater and saline systems. The suitability of red hybrid tilapia for brackishwater and seawater culture is a reflection of the salinity tolerance inherited from the moderately (*O .niloticus* and *O. aureus*) and highly tolerant (*O. mossambicus* and *O. hornorum*)tilapia species (Philippart and Ruwet, 1982; Payne, 1983; Wohlfarth and Hulata, 1983; Stickney, 1986a). Nile tilapia can tolerate dissolved oxygen (D.O.)

levels down to 0.3 mg/L (Popma and Masser, 1999). Despite this ability to survive acute low D.O. concentrations, tilapia systems should be managed to maintain D.O. above 2 mg/L because chronic exposure to low D.O.depresses metabolism, growth and disease resistance (Teichert-Coddington and Green, 1993). The pH should be managed for best growth in the range of 6 to 9 (Guerrero, 1997; Popma and Masser, 1999). However, tilapia can tolerate pH from 5-11 (Bardach et al., 1972). Un-ionized ammonia (NH_3) levels can suppress feeding at 0.08 mg/L (Popma and Masser, 1999). Chronic exposure to NH_3 levels $\geq$ 1 mg/L cause mortality especially among juveniles and fry (Popma and Masser, 1999). Evans et al. (2006) reported the LC50's of NH_3 for *O. niloticus* were 1.46 mg/L at 24 h, 1.33 mg/L at 72 h and 0.98 mg/L at 96h. Wang et al. (2006) reports the LC50 of nitrite (NO_2) for *O. niloticus* at 28.18 mg/L. It should be noted that chloride reduces the toxic affect of NO_2 (Russo and Thurston 1977; Yanbo, 2006). Chloride (Cl) should be managed in earthen ponds at levels of 10:1 (Cl: NO_2) (Durborow et al., 1997). As a safeguard in recirculating systems, Cl levels are often maintained from 100-150 mg/L (Popma and Masser, 1999).

Nutrition

There have been several reviews of the nutrition and feeding of tilapia in commercial operations (Ulloa, 1995; Diana, 1997; Lim, 1997; El-Sayed, 2006). Early tilapia production systems relied on natural food organisms as the source for nutrition (Lim and Webster, 2006). These early production systems were extensive in nature. As the industry expands and the technology development continues, traditional extensive culture of tilapia is being replaced by semi-intensive and intensive production systems. In semi-intensive farming systems, supplemental feeds that consist of locally available, low-cost single feedstuffs, such as rice bran,

copra meal, coffee pulp, brewery by-products and/or their combination, are generally used as supplements to natural food (Lim, 1989). As stocking rate increases, the contribution of natural food decreases and more nutritionally complete feeds are needed. In intensive culture systems such as in ponds, raceways, cages and tanks, feed is the most expensive item, often ranging from 30 to 60 percent of the total variable expenses, depending on the intensity of the culture operation (Lim and Webster, 2006). Thus, the availability of least cost, nutritionally well-balanced feeds is one of the most important requisites for successful and sustainable tilapia production (Lim and Webster, 2006).

Proteins are the principal organic constituent of animal tissue and are the most expensive component in fish diets (Lim and Webster, 2006). Several factors including fish size or age, dietary protein source, energy content, water quality and culture conditions have been reported to affect protein requirements of tilapia (NRC, 1993). The protein requirement for maximum performance of tilapia during larval stages is relatively high (35 - >50%) and decreases with increasing fish size (Winfree and Stickney, 1981; Jauncey and Ross, 1982; Siddiqui et al., 1988; El-Sayed and Teshima, 1992). For tilapia juveniles, the protein requirement ranges from 30-40%, while adult tilapias require 20-30% dietary protein for optimum performance. Tilapia broodstock require 35-45% dietary protein for optimum reproduction, spawning efficiency, and larval growth and survival (Gunasekera et al., 1996a, b; Siddiqui et al., 1998a, b; El-Sayed et al., 2003).

Tilapias require the same ten essential amino acids (arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) as other fish and terrestrial animals (Lim and Webster, 2006). The quantitative requirements for these essential amino acids have been determined for *O. mossambicus* (Jauncey et al., 1983) and *O. niloticus* (Santiago and Lovell, 1988).

Vitamins are organic compounds that are required in small amounts for normal growth, reproduction and health (Lim and Webster, 2006). Tilapia, stocked at light to moderate densities in fertilized earthen ponds, obtain required vitamins from natural food organisms (Shiau and Lin, 2006). Natural food organisms become limited in intensive culture, cannot provide vitamin requirements and vitamins must be provided as part of the formulated diet (Shiau and Lin, 2006). There are two basic categories of vitamins: water-soluble and fat-soluble. Water-soluble vitamin requirements of tilapia are: thiamin (B_1), riboflavin (B_2), niacin (B_3), pantothenic acid (B_5), pyridoxine (B_6), biotin (B_7), folic acid (B_9), cobalamin (B_{12}), inositol (B_h), choline and L-ascorbic acid (C) (Lim and Webster, 2006). Fat-soluble vitamin requirements of tilapia that have been studied are: retinol (A), cholecalciferol (D_3), tocopherol (E) and ketamine (K) (Shiau and Lin, 2006).

Deficiencies of vitamin B_1 in red hybrid tilapia (*O. mossambicus* x .*O niloticus*) fingerlings cultured in seawater (32 g/L) resulted in reduced growth and feed efficiency and low hematocrit (Shiau and Lin, 2006). A thiamin level of 2.5 mg/kg of diet was sufficient for maximum growth and prevention of deficiencies (Lim et al., 1991).

Clinical signs reported for tilapia fed a vitamin B_2 free diet were anorexia, poor growth, high mortality, fin erosion, loss of normal body color, dwarfism and cataracts (Shiau and Lin, 2006). The riboflavin requirements were 6 mg/kg of diet for juvenile *O. aureus* grown in freshwater (Soliman and Wilson, 1992a) and 5 mg/kg of diet for *O. mossambicus* x *O. niloticus* grown in seawater (32 g/L) (Lim et al., 1993).

Vitamin B_3 is a dietary essential for *O. niloticus* x *O. aureus* hybrid but the level required varies depending on the source of dietary carbohydrate (Shiau and Lin, 2006). Optimum dietary level for maximum growth have been reported to be 26 mg niacin/kg diet for fish fed a glucose

diet and 121 mg niacin/kg of diet for fish fed a dextrin diet (Shiau and Lin, 2006). Fish deprived of dietary niacin developed hemorrhages, a deformed snout, gill edema and skin, fin and mouth lesions (Shiau and Suen, 1992). The optimum level for maximum growth have been reported to be 26 mg niacin/kg diet for fish fed a glucose diet and 121 mg niacin/kg of diet for fish fed a dextrin diet (Shiau and Lin, 2006).

Clinical signs of vitamin B_5 deficiencies include poor growth, hemorrhage, sluggishness, high mortality, anemia and gill hyperplasia (Soliman and Wilson, 1992b). A dietary level of 10 mg of calcium pantothenate/ kg of diet is sufficient for optimal health of *O. aureus*. (Soliman and Wilson, 1992b).

Clinical signs reported for tilapia fed a vitamin B_6 free diet were abnormal neurological signs, anorexia, ataxia, convulsions, caudal fin erosion, mouth lesions, hyperirritability, poor growth and high mortality (Shiau and Lin, 2006). Weight gain and hepatic alanine aminotransferase activity analyzed by broken line regression indicated that the optimum dietary pyridoxine requirement of juvenile *O. niloticus* x *O. aureus* reared in freshwater were 1.7-9.5 mg/kg of diet and 15.0-16.5 mg/kg of diet containing 28% and 36% protein, respectfully (Shiau and Hsieh, 1997). A pyridoxine level of 3 mg/kg of diet was reported to be adequate for *O. mossambicus* x *O. niloticus* fed 38% protein diets and reared in seawater (32 g/L) (Lim et al., 1995).

Vitamin B_7 is important for the metabolism of amino acids, carbohydrate and lipids (Shiau and Lin, 2006). Deficiency signs include poor growth and reduced hepatic pyruvate carboxylase and acetyl CoA carboxylase activities (Shiau and Chin, 1999). The biotin requirement for maximum growth of *O. niloticus* x *O. aureus* has been estimated to be 0.06 mg/kg of diet (Shiau and Chin, 1999).

Vitamin B_9 is important in amino acid and nucleotide metabolism and is essential for normal cell division and multiplication (Shiau and Lin, 2006). Deficiency signs include poor growth and reduced feed intake and efficiency (Lim and Klesius, 2001). An analysis of the weight gain percentage by broken line regression indicates that the adequate dietary folic acid requirement of *O. niloticus* x *O. aureus* is 0.82 mg/kg of diet (Shiau and Huang, 2001). The folic acid requirement for *O. niloticus* is 0.5 mg/kg of diet (Lim and Klesius, 2001).

Choline is essential for the synthesis of various methylated metabolites and a precursor of acetylacholine (Shiau and Lin, 2006). Clinical signs of choline deficiencies include poor growth, and survival, reduced blood triglyceride, cholesterol, and phospholipid concentrations (Shiau and Lo, 2000). The optimum choline for *O. niloticus* x *O. aureus* is 1,000 mg/kg of diet (Shiau and Lo, 2000).

Tilapias do not have a dietary requirement for vitamin B_{12}. It is produced in their gastrointestinal tract through bacterial synthesis (Lovell and Limsuwan, 1982; Sugita et al., 1990; Shiau and Lung, 1993).

Vitamin B_h is classified as a vitamin-like nutrient and is often added as a supplement to aquatic feeds (Shiau and Lin, 2006). Perres et al. (2004) reports that *O. niloticus* does not have a dietary requirement for inositol. Shiau and Su (2005) report that the inositol requirement of *O. niloticus* x *O. aureus* to be 400 mg/kg of diet.

Clinical signs of vitamin C deficiency in tilapias include lordosis, scoliosis, poor growth and wound healing, reduced feed efficiency, hemorrhage, anemia, exophthalmia, and gill and opercular deformities (Stickney et al., 1984; Shiau and Jan, 1992; Shiau and Hsu, 1999). The vitamin C requirement for *O. niloticus* is 50 .0mg/kg of diet (Stickney et al., 1984). The vitamin

C requirement for *O. aureus* is 79.0mg/kg of diet (Shiau and Jan, 1992). The vitamin C requirement for *O. niloticus* x *O. aureus* is 19.0 mg/kg of diet (Shiau and Hsu, 1999).

Vitamin A is important in a number of physiological processes including vision, reproduction and in the maintenance of differentiated epithelia in vertebrates (Shiau and Lin, 2006). Clinical signs of retinol deficiency in tilapias include poor growth, reduced feeding efficiency, high mortality, restlessness, abnormal swimming, exophthalmia, blindness, hemorrhage of the eyes, fins and skin and reduced mucous secretion (Shiau and Hwang, 1993). The retinol requirement of juvenile Nile tilapia has been reported as 5,000 IU/kg of diet (Saleh et al., 1995). The retinol requirement of *O. niloticus* x *O. aureus* is 5,850-6,970 IU/kg of diet (Hu et al., 2006).

Vitamin D_3 functions to stimulate the absorption of calcium from the intestine (Shiau and Lin, 2006). Optimum cholecalciferol requirement for maximum growth of *O. niloticus* x *O. aureus* is 374.8 IU/kg of diet (Shiau and Hwang, 1993). O'Connell and Gatlin (1994) reported that dietary D_3 is not essential for *O. aureus*.

Vitamin E functions as an anti-oxidant (Shiau and Lin, 2006). Clinical signs of tocopherol deficiency in *O. aureus* include anorexia, reduced weight gain and diet efficiency, skin hemorrhages, impaired erythropoiesis, muscle degeneration, ceroid in liver and spleen and abnormal skin coloration (Roem et al., 1990). The vitamin E requirement of *O. aureus* was estimated at 10 mg and 25 mg dl-α-tocopherol acetate/kg of diet in diets containing 3% and 6% dietary lipid, respectfully (Roem et al., 1990c). The vitamin E requirement of *O. niloticus* was reported to be 50 to 100 mg/kg of diet for a diet containing 5% lipid, increasing to 500 mg/kg of diet for a diet containing 10-15% lipid (Satoh et al., 1987).

Vitamin K has a role in coagulation of blood and in calcium transport (Shiau and Lin, 2006). Tilapia showed poor growth and low plasma prothrombin when fed a ketamine-free diet for 8 weeks (Lee, 2003). The vitamin K requirement of *O. niloticus* x *O. aureus* is estimated to be 5.2 mg/kg of diet (Lee, 2003).

Information on the dietary mineral requirements for tilapia is limited. The minerals which have been evaluated include: magnesium (Mg), manganese (Mn), potassium (K), iron (Fe), copper (Cu) and zinc (Zn).

Dietary Mg levels of 0.59 to 0.77 g/kg of diet for Nile tilapia (Dabrowski et al., 1989) and 0.5 to 0.65 g/kg of diet for blue tilapia (*O. aureus*) (Reigh et al. 1991) have been reported to be adequate. Excessive levels of Mg (3.2 g/kg) when fish were fed low (24%) protein diets have resulted in depressed growth, low hematocrit and hemoglobin and sluggishness (Dabrowski et al., 1989). Fish that were fed Mg-deficient diets had poor growth, low tissue Mg concentrations and abnormal tissue mineralization (Lim and Webster, 2006).

Dietary Mn has been reported for *O. mossambicus* at 1.7 mg/kg/day of diet (Ishac and Dollar, 1967). Watanabe et al. (1988) recommended a dietary level of 12 mg/kg of diet for *O. niloticus*. Deficiency of Mn resulted in anorexia, poor growth, loss of equilibrium and high mortality (Lim and Webster, 2006).

The dietary requirement of Fe is affected by the source of Fe (Lim and Webster, 2006). Shiau and Su (2003) recommend that 150 to 160 mg/kg of diet from iron citrate meets the Fe requirements for hybrid tilapia (*O. niloticus x O. aureus*). A minimum level of 60 mg/kg of diet was suggested to maintain normal erythropoiesis in Nile tilapia (Kleeman et al., 2003).

The dietary requirement of K for optimum growth, gill Na^+-K^+ ATPase activity and whole-body K retention of hybrid tilapia (*O. niloticus x O. aureus*) was reported as 0.2-0.3 g/kg

of diet (Shiau and Hsieh, 2001). The requirements of *O. niloticus* for Zn have been reported to be 30 mg/kg of diet (Elhamid Eid and Ghonim, 1994). A dietary Cu level of 2 to 3 mg/kg has been suggested by Watanabe et al. (1988) for *O. niloticus*, although the requirement has not been determined.

Fish Health

Nile tilapias are susceptible to a variety of parasitic, bacterial, fungal and viral pathogens. For a complete listing of tilapia pathogens see the following website: http://www.fishbase.org/Diseases/diseasesList.cfm?ID=2&StockCode=1

Shoemaker et al. (2006) suggests that the following can prevent, control or limit the effects of disease causing agents: quarantine of new fish stocks, cleanliness of culture facility, maintenance of water quality parameters within normal limits, nutritionally balanced diets and proper feeding strategy, proper stocking rates, the use of chemotherapy or antibiotics and vaccination. It must be noted that tilapia fry are sensitive to handling. Commonly reported problems during the fry to fingerling phase of tilapia production include protozoan parasites: *Trichodina spp*., *Epistylis spp*., *Icthyobodo spp*. and *Ichthyophthirius multifilis* (Green, 2006). These protozoan parasites affect the skin and gills and are best treated with multiple (temperature dependant) static applications of formalin (25-50 ml/m^3) or sodium chloride (non-iodized and no anti-caking agents) at 3g/L (Conroy and Herman, 1970; Tonguthai and Chinabut, 1997). Common bacterial pathogens include: *Aeromonas hydrophila*, *Flexibacter columnaris*, *Pseudomonas spp*. and *Streptococcus spp*.. Tilapia growers consider streptoccal diseases caused by *S. iniae* and *S. agalactiae* the most serious economic threat (Klesius et al. 2000; Shoemaker et al. 2000, 2001; Evans et al. 2002). Treatments with potassium permanganate at a rate of 2-4

mg/L are sometimes useful for external infections. However, systemic infections can only be treated with medicated feeds (Camus et al., 1998). Currently there are only two antibiotics approved for the use in medicated feeds: oxytetracycline and sulfadimethoxine (USFDA, 2010).

The same pathogens that affect fry and fingerlings also affect fish in the grow-out phases of production. Viral pathogens are another group which can affect tilapia. The Iridovirus group causes lymphocytis (bumps on the skin) (Shoemaker et al., 2006). The condition is not lethal but negatively impacts marketability. A whirling viral disease of tilapia fry has been reported by Avtalion and Shlapobersky (1994) to have caused mortality in laboratory reared *O. aureus*, *O. niloticus*, *S. galilaeus* and tilapia hybrids including red tilapia. Currently, there are no available treatments for these viral pathogens (Shoemaker et al., 2006).

Production Characteristics

Some culture advantages of tilapia are that it feeds low on the food chain, accepts wide range of feeds, is resistant to poor water quality and disease, responds well to handling, has a good flesh quality and that fingerlings are easy to produce year round (Popma and Masser, 1999). Some culture disadvantages are that they are sensitive to low water temperatures (Popma and Masser, 1999), reaches sexual maturity at a young age (Popma and Masser, 1999), males grow faster than females (Baras and Melard, 1997; Ponzoni et al., 2005; Toguyeni et al., 2002), and are difficult to harvest from earthen ponds with a seine (Sifa et al., 1999).

Tilapia are produced by near-subsistence farmers as a savings account for hard times; caught and consumed by subsistence fishermen; raised and sold to local village markets and upscale domestic markets; exported to high-end sales outlets in the United States (U.S.), Japan, and Europe; and raised by hobby farmers in the U.S. and Europe (Engle, 2006). Tilapia are

considered, often in the same countries, as low-priced products for the poor; as ethnic products; and as gourmet, luxury, upscale products for white tablecloth restaurants. Tilapias are undoubtedly the most ubiquitous, the most successful, and the most adaptable aquaculture species in the world.

Tilapias are sexually dimorphic relative to growth (Baras and Melard, 1997; Ponzoni et al., 2005; Toguyeni et al., 2002). Males tend to grow faster and larger, in part, due to females becoming sexually mature sooner. Therefore, when culture is in the grow-out phase of production it is optimal to have all male populations. This is achieved by manually sexing fish, sex reversal of fry (Phelps, 2006), hybridization (female *O. niloticus* X male *O. hornorum*) (Hickling, 1960; Lovshin, 1982) and producing genetically male tilapia (GMT) (Mair et al., 1995). GMT "super males" are produced by three sequential crosses. The process requires all progeny to be kept separated until sexual identification and quantification can be accomplished. This requires strict record keeping and plenty of space.

Broodstock Management

Shelton and Popma (2006) describe *Oreochromis spp.* as paternal nesting substrate spawners and maternal mouth brooders. The males exhibit conspicuous breeding colors. Male and female papillae are dimorphic in terms of size, shape and structure. The mating system of the African cichlid fish *Oreochromis spp.* resembles that of other lekking animals; males defend mating territories where they excavate sites for mating and oviposition (Baerends and Baerends-van Roon, 1950; Fryer and Iles, 1972). Females lay eggs in the excavated site, after which they are fertilized by the male. Under natural conditions, females may encounter solitary or aggregated males and experience varying degrees of male interference and competition during

courtship and spawning (Nelson, 1995). After fertilization of the eggs, the female picks up the eggs in her buccal cavity. Thereafter, the female leaves the spawning bed and rears her clutch until the fry are free-swimming. The male continues to defend the bed and attract other females for mating (Fryer and Iles, 1972; Rana, 1988).

Nile tilapias reach sexual maturity in natural lakes at 10-12 months (350-500g) and in small ponds at 5-6 months (150-200g) (Jalabert and Zohar, 1982; Philippart and Ruwet, 1982; Rana, 1988; Brummett, 1994). Optimal spawning temperature is 25-30^{o}C and does not occur at < 20 ^{o}C (Green et al., 1997). The relative fecundity of *Oreochromis spp*. is low at 6,000-13,000 eggs/kg of female/spawn (Siraj et al., 1983). This is compensated by the high level of maternal care (i.e. high survival) and their asynchronous spawning behavior. When females spawn asynchronously, as reported with the Japanese medaka (*Oryzias latipes*), individual males with high competitive ability can potentially acquire access to a disproportionately large share of the total number of females that spawn in a given period of time (Grant et al., 1995). Mating systems can strongly influence effective population size (Ne), by affecting the likelihood that an individual will reproduce (Nunney, 1991), by influencing the variance in individual reproductive success within one or both sexes (Nunney, 1993) and by affecting the number of mates per individual (Sugg and Chesser, 1994). Higher fecundity and higher reproductive success of a few parents may result in a quite high variance in progeny number and consequently small within-generation Ne and low Ne/N ratio (Waples, 1998). When Ne is low, there is considerable risk that the amount of genetic variation in the population will be reduced by genetic drift (Hedrick, 2005). There is a direct relationship between Ne and inbreeding, such that Ne is equal to 1/ (2ΔF), where ΔF is the per-generation rate of inbreeding (Falconer and Mackay, 1996). To

ensure the long-term success of breeding programs, the maintenance of genetic variation is very important (Hedrick et al., 1986).

Maintaining pure, high-quality broodstock is essential to the production of any species. El-Sayed (2006) suggests the following measures/characteristics to consider in broodstock selection: genetic purity, size, age and quality.

Purity is maintained through methodical record keeping of fish movements and by filtering incoming waters to reduce the incidence of feral gene incorporation. Selected individuals should be free of deformity and injury. Inadequate breeding numbers can result in inbreeding depression that manifests as poor growth, poor survival and the presence of abnormalities (Hulata et al,. 1986; Teichert-Coddington and Smitherman, 1988; Eknath et al., 1993; Lovshin 2000; Pante et al. 2001; Brummett, 2004). Smitherman and Tave (1987) reported that maintenance of an effective breeding number of 100-150 broodfish sustains 99% of genetic variability and reduces inbreeding depression.

Size of female is more important than age in terms of fecundity and total number of eggs produced (Rana, 1986 and Rana, 1988). Some authors have indicated that number of eggs produced is related to body length (Lowe-McConnell, 1955; Welcomme, 1967; DeSilva, 1986; Rana, 1986) while others have claimed that it is more related to the body weight of the female (Peters, 1983; Rana, 1988). However, relative fecundity decreases with maternal age, weight and length (Rana, 1986). Nile tilapia females of larger size were found to produce more and bigger eggs (Rana, 1986) and more fry per female (Guerrero and Guerrero, 1985), but smaller females spawn more frequently (Guerrero and Guerrero, 1985).

Relative size of males and females may be more important as there are often hierarchies (Noakes and Balon, 1982) in tilapia populations based on the social dominance, which is

partially determined by fish size. Male tilapias are aggressive in nature and dominant males control most of the spawning, resulting in many females not spawning. The hierarchy affects the intensity of spawning and these effects may be greater in clear water systems compared to green water systems (Little, 1989). Provision of artificial nests (Bevis, 1994) helps to break hierarchies; thus, more females may have contact with more males and spawn. The hierarchy can also be minimized by spawning females with smaller (Guerrero and Guerrero, 1985) and uniformly-sized males.

In commercial seed production, medium-size tilapia broodfish (150–250 g) are preferred (Bhujel, 2000). However, many broodfish can start to breed when they are as small as 60 g, which can be achieved within a maturation period of 6 months after hatching (Bhujel, 2000). Broodfish are usually discarded after attaining more than 300 g as bigger fish are difficult to handle during harvesting of seed (Bhujel, 2000).

Fry Production

Tilapia fry are typically produced in earthen ponds, tanks and hapas. Selection of production system is relative to the life stage that will be collected. Mixed size fry (sac to swim-up) are typically collected from earthen ponds. Fertilized eggs and sac fry are typically collected from brooders held in hapas and tanks. Production in earthen ponds is relatively extensive. Production in hapas and tanks is more intensive, though daily production is generally higher.

Snow and Phelps (1996) suggested that ponds be prepared in advance before stocking broodfish. The ponds should be devoid of predators and have an established plankton bloom. Stocking should commence once temperatures have stabilized over 22^{o}C. Nile tilapias are highly polygamous. The ponds should be stocked at a density range from 1,000-5,000 fish/ha with 100

+g fish at the sex ratio of 3-4 females per male. Other broodfish stocking strategies suggest that earthen ponds be stocked at a broodfish biomass ranging from 150 to 2,000 kg/ha (3,000 to 10,000 fish/ha) at the sex ratio of 1-4 females per male (Broussard et al., 1983; Mires, 1983; Little, 1989; Green et al., 1994; Hulata, 1997). Broodfish are fed at 1-2% biomass/day with additional fertilizers to maintain bloom. They should begin to spawn within 5 days after stocking. Partial harvesting of ponds should be carried out on weekly to monthly intervals. Increased frequency of harvest generally increases production and reduces size variability. Based on frequency of harvest, Green (2006) describes yields of hybrid tilapia (*O. niloticus* x *O. hornorum*) from 0.05 ha earthen ponds ranging from 0.9 -2.2 fish/m^2/day.

Popma and Green (1990) describe the procedure for complete or drain harvesting fry. They do not recommend attempting a drain fry harvest in ponds without a harvest basin. The protocol begins with eliminating nuisance fish species from the resource. A large mesh netting is draped and secured to the bottom of harvest basin for ease of separating brood from fry at draining. For yields of 50,000 fry, they recommend stocking 35-55 kg of mature females and sufficient males; so, the sex ratio is 1 male to 1.5 to 2 females. The pond area to safely handle this biomass is 500-1,000 m^2. The ponds should be drained 14-23 days after stocking of brood. The brood animals are removed first with the large mesh net followed by netting of fry.

Tank culture of tilapia is a good alternative to pond or cage culture if sufficient water or land is not available and the economics are favorable (Rakocy, 1989). Tanks with flowing water have been successfully used to produce commercial quantities of sex reversed fry (Rothbard et al. 1983; Guerrero and Guerrero, 1988). Tanks can be constructed from a wide range of materials. The most common are constructed of concrete, fiberglass, wood or plastic polymers. Broodfish stocking rates vary from 3-10 fish/m^2 and sex ratios from 1-10 females per male

(Guerrero and Guerrero, 1985; Bautista et al., 1988; Little et al., 1993). Broodfish are fed 30-45% crude protein floating extruded feed at 1-2% of fish biomass once or twice daily (Bhujel, 2000; Green and Engle, 2000; Ridha and Cruz, 2000). Daily yield of fry increases as the frequency of harvest is increased. Guerrero and Guerrero (1985) reported yields of 8-16 seed/m^2 where fry are harvested daily from concrete tanks stocked at 347 g/m^2 with a 1:1 sex ratio over a 50-72 day breeding period. Little et al. (1993) reported seed (free-swimming fry, fertilized eggs and fry from the mouths of females) yields up to 106 seed/kg/day over a 155-day breeding period where brood fish (*Oreochromis niloticus* Chitralada strain) (3-18 months of age); (70-300g/fish) were obtained from earthen ponds and held in conditioning tanks (recirculating bio-filter system) then transferred to spawning tanks (recirculating bio-filter system) maintaining a density of 8 fish/m^2 (sex ratio = 1:1) where seed were harvested every 10 days and spent females were replaced from conditioning tanks. When spent females were replaced from conditioning tanks every 10 days reproductive rates were further increased to 160 seed/kg/day and 274 seed/kg/day when all females were replaced.

Hapas are nets (typically 2-3 mm mesh) suspended in a body of water to enclose fish. They are relatively inexpensive and easily harvested. However, additional facilities are required for the care of eggs harvested from within. In addition, water quality within hapas can deteriorate if the mesh is allowed to become clogged with organic materials (Lovshin and Ibrahim, 1988). The broodfish should be stocked at 1-4 females per male from a density range of 1-12.5 fish/m^2 (Guerrero and Garcia, 1983; Lovshin and Ibrahim, 1988; Little, 1989; Behrends et al., 1993). Broodfish are fed 30-45% crude protein floating extruded feed at 1-2% of fish biomass once or twice daily (Bhujel, 2000; Dan and Little, 2000a; Little et al., 2000). Daily yields of tilapia seed, comprised of fertilized eggs through swim-up fry, vary from 2-86

seed/m^2, but generally range from 35-86 seed/m^2 from harvest intervals of 5 -21 days (Guerrero and Garcia, 1983; Lovshin and Ibrahim, 1988; Little, 1989; Behrends et al., 1993). Little (1989) reported yields from hapas within earthen ponds of 42-84 seed/m^2 where free-swimming sac fry are harvested and up to 239 seed/m^2 where eggs and sac-fry were harvested from tank and mouths of females every 10 days over a 60-day period.

Fry To Fingerling Management

There is a need for mixed sex fingerlings. Fry and fingerling production can be approached from several directions. In the production of mixed sex fingerlings, Snow and Phelps (1996) discuss how the first spawn may reach 2.5-5.0 cm in 30-50 days. Once the first spawn are above 1g/each, partial harvests can be made every 10 days using a 6 mm non-treated seine. After 9-12, weeks the yield of fry will begin to decrease and a complete harvest is recommended. More frequent partial harvests serve to maintain more uniform population size structure, which reduces the occurrence of cannibalism of smaller fry by larger fingerlings (Green, 2006). The overall production should average between 3-9 fish/m^2/month depending on the effectiveness of partial harvests and pond fertility.

Snow and Phelps (1996) discussed the use of nursery ponds for rearing small (1g) to 10-25g fingerlings. When fry are collected, they should be stocked into organically fertilized ponds at 200-500 fry/m^2 and given a supplemental feed. After 30 days, the fish should average 1 g depending on survival and quality and quantity of feed and fertilizer. Fertilization rates equivalent to 200 kg/ha (dry wt.) of chicken manure are appropriate with a maximum feeding rate of 50-75 kg/ha/day. Tilapia fry survival of 60-70 % can be anticipated. Larger fingerlings are produced by restocking the 1g fish at a density of 10-20 fry/m^2 with a culture period of 60-90

days. The food supply, time availability, size desired and productivity of the facility are considered in stocking a secondary rearing pond. A carrying capacity of 3,000 kg/ha with an average survival of 75 % (range = 60-95%) should be assumed.

The length of culture period is a function of growth rate (Snow and Phelps, 1996). If the average daily gain is 30 kg/ha, about 100 days would be needed to rear 100,000 fish to a size of 30 g. The rate of gain can be regulated to some extent by the amount of food provided. However, overfeeding tends to increase food conversion ratio (FCR) resulting in less economic return from feed input. Production rates of gain > 30 kg/ha/day are not uncommon for certain combinations of stocking rates and nutrient inputs.

All male populations are desired in grow-out phases of tilapia food fish culture. As described by Phelps (2006), all male populations of tilapia can be produced by controlling the gonadal development at an early point (before 14-22 mm TL) in its life history development. As tilapia fry begin to swim-up and feed, the gonadal tissue has not developed into ovary or testis and is sensitive to sex steroids that can be administered to control the phentotypic sexual development. The most commonly used androgens are methyl-testosterone and ethynyl-testosterone. The most commonly used delivery method is hormone incorporation into high quality/palatable feed. Hormone treatment must continue until differentiation is complete, this may take 2-4 weeks.

Fingerling to Grow-Out Management

Production strategies evolve continuously. Therefore, producers must analyze technical, economic and marketing constraints to develop sound production/business plans. Among the technical considerations are the type, size and conformation of the production unit to be utilized

(Green and Duke, 2006). Tilapia fingerlings are typically grown out to marketable food sizes in earthen ponds, submerged (lotic and lentic) cages, and tanks.

Expected yields of tilapia are quite variable relative to the respective intensity of the production system cultured. Typical carrying capacity for earthen ponds range from 10,000-30,000 /ha (Green and Duke, 2006) and stocking density ranging from 1-3 fish/m^3 (Lovshin, 2000). Growth rate in earthen brackish water ponds was reviewed by Green and Duke (2006) for two growth phases of sex-reversed *Oreochromis sp*. Growth rate for phase I (0-200g/fish) fry stocked at 4 fish/m^2 for 77 days was reported as 1.2 g/day. Growth rate for phase II (200-1,000g/fish) stocked at 1 fish/m^2 for 210 days was reported as 4 g/day. Typical carrying capacity for tilapia cultured in flow-through tanks range from 2.04 -2.86 kg/L (Soderberg, 2006) and stocking density ranging from 10-50 fish/ m^3 (Lovshin, 2000). Soderberg (2006) estimated growth rate of 1.16 mm/day (2.5 g/day) for *O. niloticus* (0-250 g) in flowing water at temperature of 28-30 ^oC. Typical carrying capacity for cage culture ranges from 250-600 kg/ m^3 (Schmitto, 2006) and stocking density ranging from 100-300 fish/ m^3 (Lovshin, 2000). Macaranas *et al*. (1997) in Fiji evaluated the production performance of mixed-sex *O. mossambicus*, Israel *O. niloticus,* Thailand *O. niloticus* and Taiwanese red tilapia hybrids in 4 m^3 cages stocked with 25 fish/m^3. Cages were placed in both fertilized and unfertilized freshwater ponds. Average stocking weight ranged between 3 and 15 g and fish in all treatments were fed a formulated diet for the 4-month experimental period. Average harvest weights from all treatments for Thailand Nile tilapia, Israel Nile tilapia, red tilapia and Mozambique tilapia were 127, 110, 91 and 60 g, respectively.

Polyculture

Polyculture has the potential to increase the final harvest weight of tilapia via stocking predators to control unwanted reproduction. In addition, overall production can be increased by stocking other species with tilapia. An increase in inputs and level of intervention can be associated with polyculture. Some examples include harvest sorting and management of tilapia as primary or secondary culture species. Primary species are usually more valuable and less tolerant to poor water quality while secondary species are usually less valuable and more tolerant to poor water quality. Tilapias may serve as primary or secondary species in polyculture systems. Where tilapias serve as the primary culture species, predators are stocked to address unwanted tilapia reproduction. Predators have been used in combination with mixed sex populations of tilapia in intensively and extensively managed ponds (Swingle, 1966; Chervinski, 1974; Dunseth and Bayne, 1978; Ramos-Henao and Corredor, 1980; Hopkins et al., 1982; McGinty, 1983, 1984). In general, predators act to increase the average size of tilapia but decrease their total production (McGinty, 1985). Where tilapias are stocked as the secondary culture species they serve as forage for the primary predator species. Some examples of compatible species in polyculture systems include *Clarius spp*., *Ictalurus punctatus*, *Piaractus brachypomus*, *Colossoma macropomum*, *Micropterus salmoides*, *Cichla ocellaris* and *Arapaima gigas* (Lovshin, 1977). In addition, number of studies have focused on determining the technical viability of polyculture of tilapia with other freshwater organisms such as carp, other cichlids (Hulata et al., 1993; Vromant et al., 2002) and crustaceans like the giant freshwater prawn (*Macrobrachium rosenbergii*) (Cohen and Ra'anan, 1983; Cohen et al., 1983; Tidwell et al., 2000) and the Australian red claw crayfish (*Cherax quadricarinatus*) (Brummett and Alon, 1994; Karplus et al., 1995; Rouse and Kahan, 1998; Barki et al., 2001, Karplus et al., 2001).

Intensive Recirculating Systems

Intensive recirculating aquaculture is becoming a more widely practiced form of aquaculture. Site-independency relative to the quantity, quality and temperature of water, cost of land or other parameters outside of acceptable ranges, market-vicinity and reduction of environmental impact has been the main drive for tilapia recirculating systems (Shnel et al., 2002). The typical recirculating or "closed" system consists of settling tanks (for solids removal), biological and/or mechanical filters (for ammonia removal), ultra-violet light (for disinfection) and aeration/degassing (blowers, air compressors or compressed oxygen) (El-Sayed, 2006). A full description of this system has been reviewed by a number of authors (Mires and Anjioni, 1997; Losordo et al., 1999; Muir et al., 2000).

Fish culture in water recirculation systems requires nitrification treatment systems that maintain acceptable levels of ammonia and nitrite for the species being cultured. Protein in fish feed contains 16% nitrogen (Overton, 1993) and is the main source of ammonia introduced into production systems. The decomposition of solid fish waste and uneaten or indigestible feed can use a significant amount of oxygen and produce large quantities of ammonia-nitrogen (Losordo et al, 1999). Wheaton et al. (1994) reviewed the nitrification systems that are commonly used and outlined their characteristic advantages. Recirculating systems must be designed to maintain adequate dissolved oxygen levels (> 6 mg/L) and minimize carbon dioxide (<20 mg/L) (Losordo et al, 1999). Colt and Watten (1988) and Boyd and Watten (1989) provide an overview of aeration and oxygenation systems used in aquaculture.

In southern Israel, commercial culture of tilapia in closed systems is carried out year-round in greenhouses, even at low water temperatures (19^{o}C) and up to 29^{o}C (Muir et al., 2000). At a stocking density of 15 kg/m^{3}, the system produces 25 kg/m^{3}/year. Rosati et al. (1993)

determined the carrying capacity and performance of a recirculating system, consisting of an 18.5 m^3 fiberglass raceway and a vertical screen filter, when stocked with Nile tilapia under commercial conditions. The fish (15g) were stocked at 263 fish/m^3. Final survival was 70%. Oxygen and unionized ammonia became limiting factors when feed approached 8 and 12 kg/day. Rosati et al. (1997) further evaluated the performance of Nile tilapia (95% males) reared in a prototype commercial-scale recirculating system. The system consisted of six raceways, with a total water capacity of 160 m^3, provided with a rotating drum with a screen filter, submerged biofilter media and pure oxygen. The fish grew from 15-20 g to 560 g in 6 months. The total yield was 11.33 Mt/year (78.8 kg/m^3/year).

Recirculating systems are characterized by the ability to support high stocking densities and high net production compared with other culture systems. However, stocking density has a significant effect on individual fish growth, survival, total production and water quality (El-Sayed, 2006). A decrease in final individual fish weight and an increase in total yield with increasing stocking density are commonly observed. Considerable variations in fish size may also occur with increasing fish density in recycle systems (Rosati et al., 1993). Suresh and Lin (1992b) evaluated the effects of stocking density on the water quality and production of all-male red tilapia juveniles (75 g) stocked in circular tanks at 50, 100 and 200 fish/m^3 for 70 days. Fish growth, feed efficiency and water quality were inversely correlated with stocking density.

Processing

The main product of tilapia processing is the fillet. Filleting yield depends on machinery efficiency, operator experience, fish shape and filleting method (El-Sayed, 2006). Souza and Macedo-Viegas (2000) evaluated the effects of four different filleting methods on the processing

yield of Nile tilapia in Brazil. The filleting methods were: (i) skinning and filleting the whole fish; (ii) filleting the whole fish and then removing the skin, (iii) skinning and filleting headless fish; and (iv) filleting headless fish and then removing the skin. The best fillets and total eatable yield (36.59 and 42.15 %, respectfully) were obtained with skinning the whole fish before filleting, followed by filleting and skinning headless fish. Skinning and filleting the whole fish also produced thicker and longer fillets compared to the other methods. The type of head cut used during processing also affects the dressout and yield of tilapia (Souza et al., 2000). The authors found that contour and oblique head cuts produced better dressout and yield than straight head cuts.

Studies into alternative strategies for the improvement of fillet yield in fish have mainly concentrated on the use of body measurements as selection-criteria related to fillet yield (e.g. Bosworth et al., 1998, Bosworth et al., 2001 and Cibert et al., 1999), but the results from these studies were only moderately positive. One main conclusion has been that the correlation between body weight and fillet weight is generally high and the correlation between body weight and fillet yield is generally low (Bosworth et al., 1998 and Cibert et al., 1999). Body measurements of fish have been the traits of interest in these studies mostly because they are descriptive with respect to the shape of an animal. The shape of an animal is not only directly related to its weight, but also has been reported to be related to fillet yield of fish (Bosworth et al., 1998, Bosworth et al., 2001 and Cibert et al., 1999). Furthemore, Rutten et al. (2005) reported on slaughter data collected from 1,884 pedigreed Nile tilapias that genetic correlation between fillet weight and body measurements was 0.89 for length, 0.70 for head length, 0.94 for width and 0.91 for corrected length. In addition, they reported that genetic correlation between fillet yield and body measurements was 0.62 for length, 0.47 for head length and 0.98 for width.

Among commercial aquaculture species, tilapia is difficult to process and has a relatively low fillet yield (Snir, 2001). Rutten et al., (2004) reported fillet yields of 34.4 % for Chitralda strain, 35% for International Development Research Center (IDRC) strain and 38% for genetically improved farm tilapia (GIFT) strain. All fish in this study were manually processed Nile tilapia, *Oreochromis niloticus* with a mean pre-processed weight of 700 g/fish. Clement and Lovell (1994) reported fillet yields of 25.4% from manually processed Nile tilapia, *Oreochromis niloticus* (585 g/fish).

References

Avtalion, R.R. and Shlapobersky, M., 1994. A whirling viral disease of tilapia larvae. Israeli Journal of Aquaculture (Bamidgeh) 46, 102–104.

Baerends, G. P., and Baerends-van Roon, J. M., 1950. An introduction to the study of the ethology of cichlid fishes. Behaviour 1, 1-242.

Balarin, J.D. and Haller, R.D., 1982. The intensive culture of tilapia in tanks, raceways and Cages, in: Muir, J.F., Roberts, R.J. (Eds.), Recent advances in aquaculture. Croom Helm, London, England, pp. 265-355.

Baras, E. and Mélard, C., 1997. Individual growth patterns of juvenile Nile tilapia, *Oreochromis niloticus*. Emergence and dynamics of sexual growth dimorphism, in: Fitzsimmons, K. (Ed.), Tilapia Aquaculture, Proceedings from the Fourth International Symposium on Tilapia in Aquaculture 9–12 May 1997, Orlando, Florida, USA.NRAES, Volume 106. pp. 169–177.

Bardach, J.E., Ryther, J.H. and McLarney, W.O., 1972. Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms, Wiley, New York.

Barki, A., Gur N. and Karplus, I., 2001. Management of interespecific food competition in fish-crayfish communal culture: the effects of the spatial and temporal separation of feed. Aquaculture 201, 343-354.

Bautista, A.M., Carlos, M.H. and San Antonio, A.I., 1988. Hatchery production of *Oreochromis niloticus* at different sex ratios and stocking densities. Aquaculture 73, 85-95.

Beardmore, J.A., G.C. Mair and Lewis, R.I., 1997. Biodiversity in aquatic ecosystems in relation to aquaculture. Aquaculture Research 28, 829-839.

Beardmore, J.A. and Shami, S.A., 1979. Heterozygosity and the optimum phenotype under stabilizing selection. Aquilo Series Zoologica, 100-110.

Bestari, Njoman, 2004. An Impact Evaluation of Genetically Improved Farmed Tilapia and Their Dissemination in Developing Countries. Operations Evaluations Department. Asian National Bank. IES:Reg 2004-20.

Behrends, L.L., Kingsley, J.B. and Price, A.H.III, 1993. Hatchery production of blue tilapia, *Oreochromis aureus*, in small suspended net hapas. Aquaculture and Fisheries Management 24, 237-243.

Behrends, L.L., Nelson, R.G., Smitherman, R.O. and Stone, N.M., 1982. Breeding and culture of the red-gold phase of tilapia. Journal of the World Mariculture Society 13, 210-220.

Bevis, R., 1994. The effect of artificial nests on reproductive performance in the Nile tilapia (*Oreochromis niloticus*, L.) spawned in net hapas. M.S. Thesis. Asian Institute of Technology.

Bhujel, R.C., 2000. A review of strategies for the management of Nile tilapia, *Oreochromis niloticus,* broodfish in seed production systems, especially hapa-based systems. Aquaculture 181, 37-59.

Bosworth, B.G., Holland, M. and Brazil, B.M., 2001. Evaluation of ultrasound imagery and body shape to predict carcass and fillet yield in farm-raised catfish. Journal of Animal Science 79, 1483–1490.

Boyd, C.E. and Watten, B.J., 1989. Aeration systems in aquaculture. CRC Critical Reviews in Aquatic Sciences 1, 425-472.

Broussard, M.C., Reyes, R., and Raguidin, F., 1983. Evaluation of hatchery management schemes for large scale production of *Oreochromis niloticus* fingerlings in Central Luzon, Phillipines, in: Fishelson, L., Yaron, Z. (Eds.), Proceedings: International Symposium on Tilapia in Aquaculture. Nazeareth, Israel, May 8-13. Tel-Aviv University, pp. 414-424.

Brummett, R.E., Alon. N.C.,1994. Polyculture of Nile tilapia, *Oreochromis niloticus*, and Australian redclaw crayfish, *Cherax quadricarinatus*, in earthen ponds. Aquaculture 122, 47-54.

Brummett, Randall, 2004. On-farm and on-station comparison of wild and domesticated Cameroonian populations of *Oreochromis niloticus*. Aquaculture 242, 157-164.

Camus, A.C., Durborow, R.M., Hemstreet, W.G., Thune, R.L. and Hawke, J.P., 1998. Aeromaonas Bacterial Infections-Motile Aeromonad Septicemia. Sothern Regional Aquaculture Center. Publication Number 478.

Chervinski, J., 1974. Sea Bass, *Dicentrarchus labrax*, a "police fish" in freshwater ponds and its adaptability to various saline conditions. Bamidgeh 26, 110-113.

Chervinski, J., 1982. Environmental physiology of tilapias, in: Pullin, R.S.V. and Lowe-McConnell, R.H. (Eds.), The biology and culture of fishes. ICLARM Conference Proceedings 7, pp. 119-128.

Chimitts, P. 1955. Tilapia and its culture: A preliminary bibliography. Fishery Bulletin 8, 1.

Cibert, C., Fermon, Y., Vallod, D. and Meunier, F.J., 1999. Morphological screening of carp, *Cyprinus carpio*, relationship between morphology and fillet yield. Journal of Aquatic Living Resources 12, 1–10.

Clement, S. and Lovell, R.T., 1994. Comparison of processing yields and nutrient composition of cultured Nile tilapia, *Oreochromis niloticus* and channel catfish, *Ictalurus punctatus*. Aquaculture 119, 299-310.

Cohen, D., Ra'anan, Z., 1983. The production of the freshwater prawn, *Macrobrachium rosenbergii*, in Israel. III. Density effects of all-male tilapia hybrids on prawn yield characters in polyculture. Aquaculture 35, 57-71.

Cohen, D., Ra'anan, Z., Barnes, A., 1983. Production of freshwater prawn, *Macrobrachium Rosenbergii*, in Israel. I. Integration into fish polyculture system. Aquaculture 31, 67-76.

Colt, J. and Watten, B., 1988. Applications of pure oxygen in fish culture. Aquacultural Engineering 7, 97-441.

Conroy, D.A. and Herman, R.L., 1970. Textbook of fish diseases. Neptune City, NJ: T.F.H. Publications.

Dabrowski, H., Meyer-Burgdorff, K., and Gunther, K.D., 1989. Interaction between dietary protein and magnesium level in tilapia,*Oreochromis niloticus*. Aquaculture 76, 277-291.

Dan, N.C. and Little, D.C., 2000a. Overwintering performance of Nile tilapia, *Oreochromis niloticus*, broodfish and seed at ambient temperatures in northern Vietnam. Aquaculture Research 31, 485-493.

Dan, N.C. and Little, D.C, 2000. The culture performance of monosex and mixed sex new season and over-wintered fry in two strains on Nile tilapia *Oreochromis niloticus* in northern Vietnam. Aquaculture 184, 221-231.

Danzmann, R.G., Ferguson, M.M. and Allendorf, F.W., 1988. Heterozygosity and comparison of fitness in a strain of rainbow trout. Biological Journal of the Linnean Society 33, 285-304.

DeSilva, S.S., 1986. Reproductive biology of *Oreochromis mossambicus* populations of man-made lakes in Sri Lanka: a comparative study. Aquaculture and Fisheries Management 17, 31–47.

Diana, J. S., 1997. Feeding strategies, in: Egna, H.S., Boyd, C.E. (Eds.), Dynamics of pond aquaculture. CRC Press, Boca Raton, Florida, pp. 245–262

Doyle, Roger, 1983. An approach to the qualitative analysis of domestication selection in aquaculture. Aquaculture 33, 167-185.

Duponchelle, F., Cecchi, P., Corbin, D., Nunez, J. and Legendre, M., 2000. Variations in fecundity and egg size of female Nile tilapia, *Oreochromis niloticus*, from man-made lakes of Cote d'Ivoire. Environmental Biology of Fishes 57, 155-170.

Dunseth, D.R. and Bayne, D.R., 1978. Recruitment control and production of *Tilapia aurea* with the predator *Cichlasoma managuense*. Aquaculture 14, 383-390.

Durborow, R.M., Crosby, D.M.and Brunson, M.W., 1997. Nitrite in Fish Ponds. Southern Regional Aquaculture Center. Publication Number 462.

Eknath, A.E., Tayamen, M.M., Palada-de Vera, M.S., Danting, J.C. and Reyes, R.A., 1993. Genetic improvement of farmed tilapias: the growth performance of eight strains of *Oreochromis niloticus* tested in different farm environments. Aquaculture 111, 171-188.

El-Sayed, A.-F.M. and Teshima, S., 1992. Protein and energy requirement of Nile tilapia, *Oreochromis niloticus*, fry. Aquaculture 103, 55-63.

El-Sayed, A. M., Mansour, C. R. and Ezzat, A. A., 2003. Effects of dietary protein levels on spawning performance of Nile tilapia, *Oreochromis niloticus*, broodstock reared at different water salinities. Aquaculture 220, 619-632.

El-Sayed, Abdel-Fattah, 2006. Tilapia Culture. CABI Publishing, Cambridge, MA, USA.

Engle, Carol R., 2006. Marketing and Economics, in: Lim, C., Webster, Carl D. (Eds.), Tilapia Biology, Culture and Nutrition. Food Products Press an Imprint of Haworth Press Inc. New York, pp. 619-645.

Evans, J.J., Klesius, P.H., Gilbert, P.M., Shoemaker, C.A., Al Sarawi, M.A., Landsberg, J., Duremdez, R., Al Marzouk, A., and Al Zenki, S. 2002. Characterization of betahemolytic group B *Streptococcus agalactiae* in cultured seabream, *Sparus auratus,* and wild mullet *Liza klunzingeri*, in Kuwait. Journal of Fish Diseases 25, 1-9.

Evans, J.J., Pasnik, D.J., Brill, G.C. and Klesius, P.H., 2006. Un-ionized Ammonia Exposure in Nile Tilapia: Toxicity, Stress Response, and Suceptability to *Streptococcus agalatiae*. North American Journal of Aquaculture 68, 23-33.

Falconer, D.S., and Mackay, T.F.C., 1996. Introduction to quantitative genetics, 4th edition. Prentice Hall, Harlow.

Fernandes, C.F., 2000. Tilapia marketing in the northern Gulf of Mexico region, in: Costa-Pierce, B.A. , Rakocy, J.E. (Eds.), Tilapia Aquaculture in the Americas, Volume 2. The World Aquaculture Society, Baton Rouge, Louisiana, United States, pp. 100-118.

Fitzgerald, W.J., 1979. The red-orange tilapia: A hybrid that could become a world favorite. Fish Farming International 6, 26-27.

Fitzsimmons, Kevin, 2006. Prospect and Potential for Global Production, in: Lim, C.,Webster, C.D. (Eds.), Tilapia Biology, Culture, and Nutrition. New York:Haworth Press, pp. 51-72.

Fryer, G., and Iles, T. D., 1972. The Cichlid Fishes of the Great Lakes of Africa: Their Biology and Evolution. Edinburgh: Oliver & Boyd.

Gajardo, G. and Beardmore, J.A., 1989. Ability to switch reproductive mode in *Artemia* is related to maternal heterozygosity. Marine Ecolgy Progess Series 55, 191-195.

Galman, O.R. and Avtalion, R.R., 1983. A preliminary investigation of the characteristics of red tilapias from the Philippines and Taiwan, in: Fishelson, L.,Yaron, Z. (Eds.), Proceedings of the International Symposium on Tilapia in Aquaculture, Nazereth, Israel, 8-13 May 1983, Tel Aviv, Israel: Tel Aviv University, pp. 291-301.

Gentili, M.R. and Beaumont, A.R., 1988. Environmental stress, heterozygosity and growth rate in *Mytilus edulis*. Journal of Experimental Marine Biology and Ecology 120, 145-153.

Getinet, G.T., 2008. Effects of maternal age on fecundity, spawning interval and egg quality of Nile tilapia, *Oreochromis niloticus*. Journal of the World Aquaculture Society 39, 671-677.

Grant, J.W.A., Bryant, M.J., and Soos, C.E., 1995. Operational sex ratio, mediated by synchrony of female arrival, alters the variance of male mating success in Japanese medaka. Animal Behavior 49, 367-375.

Green, B.W. and Duke, III, C.B., 2006. Pond Production, in: Lim, C.,Webster, C.D. (Eds.), Tilapia Biology, Culture, and Nutrition, New York: Haworth Press, pp. 181-210.

Green, B.W., and Engle, C.R., 2000. Commercial tilapia aquaculture in Honduras, in:Costa-Pierce, B.A., Rakocy, J.E. (Eds.), Tilapia aquaculture in the Americas. Volume 2. Baton Rouge, LA: The World Aquaculture Society, pp. 151-170.

Green, B.W., Teichert-Coddington, D.R., and Hanson, T.R., 1994. Development of semi-intensive aquaculture technologies in Honduras. International Center for Aquaculture and Aquatic Environments Research and Development Series. Number 39. Auburn University, Alabama.

Green, B.W., Veverica, K.L. and Fitzpatrick, M.S., 1997. Fry and fingerling production, in: Egna, H.S., Boyd, C.E. (Eds.), Dynamics of pond aquaculture. CRC Press, Boca Raton, FL, pp. 215-243.

Guerrero, R. D. III. 1997. A Guide to Tilapia Farming. Aquatic Biosystems. Bay Laguna, Philippines.

Guerrero, R.D. and Garcia, A.M., 1983. Studies in the fry production of *Sarotherodon niloticus* in a lake-based hatchery, in: Fishelson, L., Yaron, Z. (Eds.), Proceedings of the International Symposium on Tilapia in Aquaculture, Nazereth, Israel, May 8-13, Tel Aviv, Israel: Tel Aviv University, pp. 386-393.

Guerrero, R.D. III, and Guerrero, L.A., 1988. Feasibility of commercial production of Nile tilapia fingerlings in Phillippines. in: Pullin, R.S.V., Bhukaswan, T., Tonguthai, K., and Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture, pp.183-186. ICLARM Conference Proceedings 15. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manilla, Phillippines.

Guerrero, R.D. III, and Guerrero, L.A., 1985. Further observations on the fry production of *Oreochromis niloticus* in concrete tanks. Aquaculture 47, 257-261.

Gunasekera, R.M., Shim, K.F. and Lam, T.J., 1996a. Effect of dietary protein level on spawning performance and amino acid composition of eggs of Nile tilapia, *Oreochromis niloticus*. Aquaculture 146, 121-134.

Gunasekera, R.M., Shim, K. F. and Lam, T.J., 1996b. Influence of protein content of broodstock diets on larval quality and performance in Nile tilapia, *Oreochromis niloticus.* Aquaculture 146, 245-259.

Gupta, M. V., and Acosta, B. O., 2004. A review of global tilapia farming practices. Aquaculture Asia, National Aquaculture Centers in Asia-Pacific, pp. 7-12.

Hedrick, Phillip, 2005. Large variance in reproductive success and the Ne/N ratio. Evolution 59, 1596-1599.

Hedrick, P.W., Brussard, P.F., Allendorf, F.W., Beardmore, J.A., Orzack, S., 1986. Protein variation, fitness and captive propagation. Zoo Biology 5, 91-99.

Hickling, C.F., 1960. The Malacca Tilapia hybrids. Journal of Genetics 57, 1-10.

Hickling, C.F., 1963. The cultivation of tilapia. Scientific American 208,143-152.

Hopkins, D.K., Pauly, D., Cruz, E.M. and Van Weerd, J.H., 1982. An alternative to predator-prey ratios in predicting recruitment. Meeresforschung 29, 125-135.

Hu, C.J., Chen, S.M., Pan, C.H. and Huang, C.H., 2006. Effects of dietary vitamin A or B-carotene concentrations on growth of juvenile tilapia *Oreochromis niloticus* x *O. aureus*. Aquaculture 253, 602-607.

Hulata, G., Wohlfarth, G. and Rothbard, S., 1983. Progeny-testing selection of tilapia broodstocks producing all-male hybrid progenies--preliminary results. Aquaculture 33, 263-268.

Hulata, G., Wohlfarth, G. W. and Halevy, A., 1986. Mass selection for growth rate in the Nile Tilapia (*Oreochromis niloticus*). Aquaculture 57, 177-184.

Hulata, G., Wohlfarth G.W., Karplus, I., Schroeder, G.L., Harpaz, S. Halevy A., Rothbard, S., Cohen, S., Israel, I., Kavessa, M., 1993. Evaluation of *Oreochromis niloticus* × O. *aureus* hybrid progeny of different geographical isolates, reared under varying management regimes. Aquaculture 115, 253-271.

Hulata, G., 1997. Large-scale tilapia fry production in Israel. The Israeli Journal Aquaculture-Bamidgeh 49, 174-179.

Ishac, M.M., and Dollar, A.M., 1967. Studies on manganese uptake in *Tilapia mossambica* and *Salmo gairdnerii*. Hydrobiologia 31, 572-584.

Jalabert, B., and Zohar, Y., 1982. Reproduction physiology in cichlid fishes, with particular reference to *Tilapia* and *Satherodon*, in: Pullin, R.S.V., Lowe-McConell, R.H. (Eds.), The biology and culture of tilapias. ICLARM Conference Proceedings, pp. 129-140.

Jauncey, K., and Ross, B., 1982. A Guide to Tilapia Feeds and Feeding. University of Stirling, Scotland.

Jauncey, K., Tacon, A.G.J., and Jackson, A.J., 1983. The quantitative essential amino acid requirements of *Oreochromis mossambicus*, in: Fishelson, L., Yaron, Z. (Eds.), Proceedings, International Symposium on tilapia in Aquaculture. Tel Aviv, Israel: Tel Aviv University, pp. 328-337.

Jhingran, V.G. and Gopalakrishnan, V., 1974. A catalogue of cultivated aquatic organisms. FAO Fisheries Tchnical Paper 130, F.A.O., Rome.

Karplus, I., Barki, A., Cohen, S., Hulata G. ,1995. Culture of the Australian red-claw crayfish, *Cherax quadricarinatus*, in Israel. Polyculture with fish in earthen ponds. The Israeli Journal of Aquaculture-Bamidgeh 47, 6-16.

Karplus, I., Harpaz, S., Hulata, G., Segev, R., Barki, A. ,2001. Culture of the Australian red-claw Crayfish, *Cherax quadricarinatus*, in Israel VI. Crayfish incorporation into intensive tilapia production units. The Israeli Journal of Aquaculture-Bemidgeh 53, 23-33.

Khater, A.A., Smitherman, A., 1988. Cold tolerance and growth of three strains of *Oreochromis Niloticus*, in: Pullin, R.S.V., Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, Volume 15. Department of Fisheries, Bangkok Thailand, and International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 215–218.

Khaw, H.L., Ponzoni, R.W. and Danting, M.C., 2008. Estimation of genetic change in the GIFT strain of Nile tilapia, *Oreochromis niloticus*, by comparing contemporary progeny produced by males born in 1991 or in 2003. Aquaculture 275, 64-69.

Kidd, M. and Hallerman, E., 2002. Growth performance of genetically male and selectively bred tilapia in recirculating aquaculture systems. Proceedings of the 4th International Conference on Recirculating Aquaculture.

Kleeman, G.A., Barros, L.E., Pezzato, F.G., Sampaio, F.G., Ferrari, J.C., Valle, J.B., Freire, E.S., and Zuanon, J.A. 2003. Iron requirement for Nile tilapia, *Oreochromis niloticus*. Book of Abstracts, World Aquaculture, May 19-23. Salvodor, Brasil. Baton Rouge, LA: World Aquaculture Society, p. 82.

Klesius, P.H., Shoemaker, C.A. and Evans, J.J., 2000. Vaccination: A health management practice for preventing diseases caused by Streptococcus in tilapia and other cultured fish, in: Fitzsimmons, K., Filho, J.C. (Eds.), Tilapia aquaculture in the 21st century. Rio de Janeiro, Brazil: Panorama da Aquicultura, pp. 558-564.

Kocher, Thomas D., 1997. Tilapia Status Report. Proceedings of the Aquaculture Species Genome Mapping Workshop, May 18-19, Dartmouth, Massachusetts.

Kocher, T.D., W.-J. Lee, H. Sobolewska, D. Penman and B. McAndrew 1998. A genetic linkage map of a tilapia, *Oreochromis niloticus*. Genetics 148, 1225-1232.

Kuo, C.M., 1984. The development of tilapia culture in Taiwan. ICLARM Newsletter 7, 12-14.

Lee, J.Y., 2003. Vitamin K requirements of juvenile tilapia, *Oreochromis niloticus* x *O. aureus* and grouper, *Epinephelus malabaricus*. Master Thesis, National Taiwan Ocean University, Keelung, Taiwan.

Li, S.F., Li, C., Dey, M., Gagalac, F. and Dunham, R., 2002. Cold tolerance of three strains of Nile tilapia, *Oreochromis niloticus* in China Aquaculture 213, 123-129.

Lim, C., 1989. Practical feeding – Tilapias, in: Lovell, T. (Ed.), Nutrition and Feeding of Fish. Van Nostrand Reinhold, New York, USA, pp. 163-183.

Lim, C., 1997. Nutrition and feeding of tilapias. in: Alston, D.E., Green, B.E. and Clifford, H.C. (Eds.), IV Symposium on Aquaculture in Central America. Asociation Nacional de Acuicultores de Honduras and the Latin American Chapter of the World Aquaculture Society, pp. 94-107.

Lim, C.E. and Klesius, P.H., 2001. Influence of dietary levels of folic acid on growth response and resistance of Nile tilapia, *Oreochromis niloticus* to *Streptococcus iniae*. November 25-30, 2001. 6th Asian Fisheries Forum, Kaohsiung, Taiwan, p. 150.

Lim, C.E. and Webster, C.D., 2006. Nutrient requirements. in: Lim, C.E. and Webster, C.D. (Eds.), Tilapia: Biology, Culture and Nutrition. Food Products Press, New York, USA, pp. 469-501.

Lim, C.E., LeaMaster, B. and Brock, J.A., 1991. Thiamin requirement of red hybrid tilapia grown in seawater, in: Abstracts. World Aquaculture Society 22 nd Annual Conference and Exposition, 16-20 June. San Juan, Puerto Rico. Baton Rouge, LA: World Aquaculture Society, p. 39.

Lim, C.E., LeaMaster, B. and Brock, J.A., 1993. Riboflavin requirement of fingerling red tilapia grown in seawater. Journal of the world Aquaculture Society 11, 451-458.

Lim, C.E., LeaMaster, B. and Brock, J.A., 1995. Pyridoxine requirement of fingerling red hybrid tilapia grown in eawater. Journal of Applied Aquaculture 5, 49-60.

Little, D.C., 1989. An evaluation of strategies for the production of Nile tilapia (*Oreochromis niloticus*) fry suitable for hormonal treatment. Doctoral dissertation, University of Stirling, Scotland.

Little, D.C., Coward, K., Bhujel, R.C., Pham, T.A., and Bromage, N.R., 2000. Effect of Broodfish exchange strategy on the spawning performance and sex steroid hormone levels of *Oreochromis niloticus* broodfish in hapas. Aquaculture 186, 77- 88.

Little, D.C., Macintosh, D.J., and Edwards, P., 1993. Improving spawning synchrony in Nile tilapia. *Oreochromis niloticus*. Aquaculture Research 24, 399-405.

Longalong, F.M., Eknath, A.E. and Bentsen, H.B., 1999. Response to bidirectional selection for frequency of early maturing females for Nile tilapia, *Oreochromis niloticus*. Aquaculture 178, 13-25.

Losordo, T., Masser, M. and Rakocy, J., 1999. Recirculating aquaculture tank production systems a review of component options. Southern Regional Aquaculture Center. Publication Number 453.

Losordo, T.M., 1997. Tilapia culture in intensive recirculating systems. in**:** Costa-Pierce, B.A., Rakocy, J.E. (Eds.), Tilapia Aquaculture in the Americas. Volume 1, Baton Rouge, Louisiana: The World Aquaculture Society, pp.185–211.

Lovell, R.T. and Limsuwan, T., 1982. Intestinal synthesis of dietary nonessentiality if vitamin B_{12} for *Tilapia nilotica*. Transactions of the American Fisheries Society 11, 485-490.

Lovshin, L.L., 1977. Progress Report on Fisheries Development in Northeast Brazil. Research and Development Series, Number 14. International Center for Aquaculture, Agricultural Experiment Station, Auburn University, Auburn, Alabama, p. 11.

Lovshin, L.L., 1982. Tilapia hybridization, in: Pullin, R.S.V., Lowe-McConnell, R.H. (Eds.), The biology and culture of tilapias. Manila Philippines: ICLARM Conference Proceedings 7. International Center for Living Resources Management, pp. 279-308.

Lovshin, Leonard L., 2000. Criteria for selecting Nile tilapia and red tilapia for culture, in: Fitzsimmons, K., Carvalho Filho, J., (Eds.), Tilapia Aquaculture in the 21st Century. Proceedings from the Fifth International Symposium on Tilapia in Aquaculture Volume 1, Ministry of Agriculture, Rio de Janeiro, Brazil, pp. 49–57.

Lovshin, L.L., and Ibrahim, H.H., 1988. Effects of broodstock exchange on *Oreochromis niloticus* egg and fry production in net enclosures, in: Pullin, R.S.V. , Bhukaswan, T., Tonguthai, K., Maclean, J.L. (Eds.), The Second International Symposium On Tilapia in Aquaculture. ICLARM Conference Proceedings 15. Department of Fisheries, Bankok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 231-236.

Lowe, R.H., 1955. The fecundity of tilapia species. The East African Agricultural Journal 21, 45–52.

Lutz, Greg C., 2006. Recent Directions in Genetics, in: Lim, C.E. and Webster, C.D. (Eds.), Tilapia Biology, Culture and Nutrition. Food Products Press an Imprint of Haworth Press Inc. New York. pp. 139-167.

Maar, A., Mortimer, M.A.E. and Van der Lingen, I., 1966. Fish culture in Central East Africa. FAO Coporate Document Number 20. Rome, Italy: Food and Agriculture Organization of the United Nations.

Macaranas, J. M., Taniguchi, N., Pante, M. J. R., Capili, J. B. and Pullin, R. S. V., 1986. Electrophoretic evidence for extensive hybrid gene introgression into commercial *Oreochromis niloticus* stocks in the Philippines. Aquaculture and Fisheries Management 17, 249-258.

Macaranas, J.M. and Fujio, Y., 1990. Strain differences in cultured fish – Isozymes and performance traits as indicators. Aquaculture 85, 69-82.

Macaranas, J.M., Mather, P.B., Lal, S.N., Vereivalu, T., Lagibalavu, M. and Capra, M.F., 1997. Genotype and environment: A comparative evaluation of four tilapia stocks in Fiji. Aquaculture 150, 11-24.

MacIntosh, D.J. and D.C. Little.1995. Nile Tilapia, *Oreochromis niloticus*, in: Bromage, N.R., Roberts, R.J. (Eds.). Broodstock management and egg and larval quality, Oxgord, U.K.. Blackwell Science, pp. 277-320.

Mair, G.C., Abucay, J.S., Beardmore, J.A. and Skibinski, D.O., 1995. Growth performance trials of genetically male tilapia (GMT) derived from YY-males in *Oreochromis niloticus*: On station comparisons with mixed sex and sex reversed male populations. Aquaculture 137, 313-323.

Mazid, M.A. Hussain, M.G. and Alam, M.J. (Eds.), 1996. Proceedings of a workshop on current status and future strategy for dissemination of genetically improved farmed tilapia in Bangladesh. Fisheries Research Institute, Mymensingh, Bangladesh.

McAndrew, B.J., 2000. Evolution, phylogentic relationships and biogeography, in: Beveridge, M.C.M., McAndrews, B.J. (Eds.), Tilapias: Biology and exploitation. London, England. Kluwer Academic Publisher, pp. 1-32.

McAndrew, B. J., 1993. Sex Control in Tilapiines, in: Roberts, R.J., Muir, J. (Eds.), Recent Advances in Aquaculture IV. Blackwell Scientific Publishing, pp. 87-98.

McAndrew, B. J., Roubal, F. R., Roberts, R. J., Bullock, A. M. and McEwen, I. M., 1988. The genetics and histology of red, blond and associated colour variants in *Oreochromis niloticus*. Genetica 76, 127-137.

McGinty, A.S., 1983. Population dynamics of peacock bass, *Cichla ocellaris* and *Tilapia nilotica* in fertilized ponds. in: Fishelson, L. and Yaron, Z. (Eds.) Proceedings, International Symposium on Tilapia in Aquaculture, 1983. Tel Aviv University Press, Tel Aviv, Israel, pp. 86-94.

McGinty, A.S., 1984. Effects of predation by tucunare (*Cichla ocellaris*) on *Tilapia nilotica* in ponds. The Journal of Agriculture, University of Puerto Rico 68, 101-105.

McGinty, A.S., 1985. Effects of predation by largemouth bass in fish production ponds stocked with Tilapia nilotica, Aquaculture, 46, 269-274.

Melard, C. and Ducarme, C., 1993. The tilapia intensive rearing technology in Europe. Special Publication, European Aquaculture Society.

Mires, D., 1983. Current techniques for the mass production of tilapia hybrids as practiced at Ein Hamifratz fish hatchery. Bamidgeh 35, 3-8.

Mires, D., 1988. The inheritance of Black Pigmentation in Two African Strains of *Oreochromis niloticus*, in: Pullin, R.S.V.,Bhukaswan, T., Tonguthai, K. and Maclean, J.L.(Eds.). The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15, 623p. Department of Fisheries, Bankok, Thailand, and Internatioanl Center for Living Aquatic Resources Management, Manila, Philippines.

Mires, D. and Anjioni, C., 1997. Technical and economic comparative evaluation of two intensive closed water-cylced culture systems for tilapias in Israel, in: Fitzsimmons, K. (Ed.), Proceedings from the fourth international symposium on tilapia in aquaculture. Northeast Regional Agricultural Engineering Service, Ithaca, New York, pp. 416-425.

Muir, J.F., Van Rijn, J., and Hargreaves, J., 2000. Production in intensive and recycle systems, in: Beveridge, M.C.M., McAndrew, B.J. (Eds.), Tilapias: Biology and Exploitation. Kluwer Academic Publishers, Dorecht/Boston/London, pp. 405-445.

Nelson, Mindy, 1995. Male size, spawning pit size and female mate choice in a lekking cichlid fish. Animal Behaviour 50, 1587-1599.

Noakes, D.L.G., Balon, E.K.. 1982. Life histories of tilapias: an evolutionary perspective. in: Pullin, R.S.V., Lowe-McConnell, R.H. (Eds.). The biology and culture of tilapias. ICLARM Conference Proceedings 7, International Center for Living Aquatic Resources Management, Manila, Philippines, pp. 61–82.

NRC (National Research Council), 1993. Nutrient Requirements of Fish. Washington, D.C.: National Academy Press.

Nunney, Leonard, 1991. The influence of age structure and fecundity on effective population size. Proceedings of the Royal Society of London. Bulletin 246, 71-76.

Nunney, Leonard, 1993. The influence of mating structure and over-lapping generations on effective population size. Evolution 47, 1329-1341.

O'Connell, J.P. and Gatlin, D.M., 1994. Effects of dietary calcium and vitamin D_3 on weight gain and mineral composition of the blue tilapia, *Oreochromis aureus* in low calcium water. Aquaculture 125, 107-117.

Osure, G.O. and Phelps, R.P., 2006. Evaluation of reproductive performance and early growth of four strains of Nile Tilapia,*Oreochromis niloticus*, with different histories of domestication. Aquaculture 253, 485-494.

Overton, J. (Editor), 1993. Nutrient requirements of fish. National Academy Press, Washington DC.

Pante, M.J.R., Gjerde, B. and McMillan, I. 2001. Inbreeding levels in selected populations of rainbow trout, *Oncorhynchus mykiss*. Aquaculture 192, 213–224.

Payne, A.I., 1983. Estuarine and salt tolerant tilapias, in: Fishelson, L.,Yaron, Z. (Eds.), Proceedings of the International Symposium on Tilapia in Aquaculture, Nazereth, Israel, Tel Aviv, Israel: Tel Aviv University, pp. 534-543.

Perres, H., Lim, C.E. and Klesius, P.H., 2004. Growth, chemical composition and resistance to *Streptococcus iniae* challenge of Nile tilapia (*Oreochromis niloticus*) fed graded levels of dietary inositol. Aquaculture 235, 423-432.

Peters, H.M.. 1983. Fecundity, egg weight and oocyte development in tilapias (Cichlidae, Teleostei). ICLARM Translations 2, International Center for Living Aquatic Resources Management, Manila, Philippines.

Phelps, Ron P. 2006. Hormone manipulation of sex, in: Lim, C.E. , Webster , C.D. (Eds.) Tilapia Biology, Culture, and Nutrition. New York: Haworth Press, pp. 211-252.

Phillippart, J.C. and Ruwet, J.C., 1982. Ecology and distribution of tilapias, in: Pullin, R.S.V. , Lowe-McConnell, R.H. (Eds.), The biology and culture of tilapias. Manila Phillipines: ICLARM Conference Proceedings 7, pp. 15-59.

Ponzoni, R.W., Hamzah, A., Tan S. and Kamaruzzaman, N., 2005. Genetic parameters and response to selection for live weight in the GIFT strain of Nile tilapia, *Oreochromis niloticus*. Aquaculture 247, 203–210.

Popma, T.J., and Lovshin, L.L., 1996. "World prospects for commercial production of tilapia". Research and Development Series 41. International Center for Aquatic Environment, Department of Fisheries and Allied Aquaculture, Auburn University,Alabama, USA.

Popma, T.J. and Green B.W. 1990. Sex reversal of tilapia in earthen ponds. Research and Development Series Number 35. International Center for Aquaculture, Alabama Agricultural Experiment Station, Auburn University, Auburn University, Alabama.

Popma, T. and Masser, M., 1999. Tilapia Life History and Biology. Southern Regional Aquaculture Center (SRAC). Publication Number 283.

Pullin, R.S.V., Capili, J.B., 1988. Genetic improvement of tilapias: problems and prospects, in: Pullin, R.S.V., Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, Volume 15. Department of Fisheries, Bangkok Thailand, and International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 259–266.

Rakocy, J.E., 1989. Tank culture of Tilapia. Southern Regional Aquaculture Center. Publication Number 282.

Ramos-Henao, A. and Corredor, G.G., 1980. Effects of three management practices on the growth and production of *Tilapia rendalli*. Bamidgeh 32, 41-45.

Rana, K.J., 1986. Parental influences on egg quality, fry production and fry performance in *Oreochromis niloticus* (Linnaeus) and *O. mossambicus* (Peters). PhD Thesis, Institute of Aquaculture, University of Stirling, UK.

Rana, K.J., 1988. Reproductive biology and the hatchery rearing of tilapia eggs and fry, in: Muir, J.F., Roberts, R.J. (Eds.), Recent Advances in Aquaculture, Volume 3. Crook Helm, London & Sydney, pp. 343–406.

Reigh, R.C., Robinson, E.H., and Brown, P.B., 1991. Effects of dietary magnesium on growth and tissue magnesium content of blue tilapia, *Oreochromis aureus*. Journal of the World Aquaculture Society 22, 192-200.

Riche, M., Weirich, C.R., Pfeiffer, T.J., Wills, P.S. and Davis, M., 2009. Trials advance low-salinity culture of cobia, pompano, other species. Global Aquaculture Advocate 12, 32-34.

Ridha, Mohammad T. 2006. Comparative study of growth performance of three strains of Nile tilapia, *Oreochromis niloticus* at two stocking densities. Aquaculture Research 37, 172-179.

Ridha, M.T. and Cruz, E.M., 2000. Effect of light intensity and photoperiod on Nile tilapia *Oreochromis niloticus* seed production. Aquaculture Research 31, 609-617.

Roem, A.J., Kohler, C.C., and Stickney, R.R., 1990. Vitamin E requirements of the blue tilapia, *Oreochromis aureus* in relation to the dietary lipid level. Aquaculture 87, 155-164.

Romana-Eguia, M.R.R. and Doyle, R.W., 1992. Genotype-environment interaction in the response of three strains of Nile tilapia to poor nutrition. Aquaculture 108, 1-12.

Rosati, R., O'Rourke, P.D., tudor, K., and Henry, R.D., 1993. Performance of a raceway and vertical screen filter while growing *Tilapia niloticus* under commercial conditions, in: Wang, J.K. (Ed.), Techniques for Modern Aquaculture. American Society of Agricultural Engineers, St. Joseph, Michigan, pp. 303-314.

Rosati, R., O'Rourke, P.D., Foley, P and Tudor, K., 1997. Operation of a prototype commercial-scale recirculating growout system for *Oreochromis niloticus,* In: Fitzsimmons, K. (Ed.), Proceedings from the Fourth International Symposium on tilapia in Aquaculture. Northeast Regional Agicultural Engineering Service, Ithaca, New York, pp. 330-347.

Rothbard, S., Solink, E., Shabbath, S., Amado, R., and Grabie,I.,1983. In: Fishnelson, L. and Yaron, Z. (Eds.), Internatioanl Symposium on Tilapia Aquaculture. Tel Aviv, Israel: Tel Aviv University, pp.425-432.

Rouse, D.B., Kahn B.M., 1998. Production of Australian red claw *Cherax quadricarinatus* in polyculture with nile tilapia *Oreochromis niloticus*. Journal of the World Aquaculture Society 29, 340-344.

Russo, R.C. and Thurston, R.V., 1977. The acute toxicity of nitrite to fishes, In: Tubb, R.A. (Ed.), Recent Advances in Fish Toxicology. Edited by U.S. Environmental Protection Agency, Ecological Research Series EPA-600/3-77-085.Corvallis, Oregon, pp. 118–131.

Rutten, M., Bovenhuis, H. and Komen, H, 2004. Modeling fillet traits based on body measurements in three Nile tilapia strains, *Oreochromis niloticus*. Aquaculture 231, 113-122.

Rutten, M., Bovenhuis, H., Komen, H. 2005. Genetic parameters for fillet traits and body measurements in Nile tilapia, *Oreochromis niloticus*. Aquaculture 246, 125-132.

Saleh, G., Eleraky, W. and Gropp, J.M., 1995. A short note on the effects of vitamin A hypervitaminosis and hypovitaminosis on health and growth of *Tilapia nilotica, Oreochromis niloticus*. Journal of Applied Ichthyology 11, 382-385.

Santiago, C.B. and Lovell, R.T., 1988. Amino acid requirements for growth of Nile tilapia. Journal of Nutrition 118, 1540-1546.

Satoh, S.T., Takeuchi, T. and Watanabe, T., 1987. Requirement of tilapia for alpha tocopherol. Nippon Suisan Gakkaishi 53, 119-124.

Schmitto, H.R., 2006. Cage Culture, in: Lim, C.E. , Webster, C. D. (Eds.), Tilapia Biology, Culture, and Nutrition. New York: Haworth Press, pp. 313-346.

Schoenen, P., 1982. A bibliography of important tilapias. (Pisces Cichhidoel for Aquaculture. ICLARM Bibliographies 3, 336p. International Center for Living Aquatic Resources Management. Manila, Phillipines.

Seyoum, S. and Kornfield, I., 1992a. Identification of the subspecies of Oreochromis niloticus using restriction endonuclease analysis of mitochondrial DNA. Aquaculture, 102, 29-42.

Seyoum, S. and Kornfield, I., 1992b. Taxonomic notes on the Oreochromis niloticus subspecies-complex with a description of a new subspecies. Cannadian Journal of Zoology, 70, 2161-2165.

Shelton, W.L., 2002. Monosex tilapia production through androgenesis. PD/ACRSP Technical Report 19, 45-51.

Shelton, W.L., and Popma, T.J. 2006. Biology, in: Lim, C. E.,Webster, C. D. (Eds.), Tilapia Biology, Culture and Nutrition. Food Products Press an Imprint of Haworth Press Inc. New York, pp. 1-27.

Shiau, S. and Chin,Y.H., 1999. Estimation of the dietary biotin requirement of juvenile hybrid Tilapia, *Oreochromis niloticus* x *O. aureus*. Aquaculture 170, 71-78.

Shiau, S. and Hsieh, H.L., 1997. Vitamin B6 requirements of tilapia, *Oreochromis niloticus* x *O. Aureus* fed two dietary protein concentrations. Fisheries Science 6, 1002-1007.

Shiau, S. and Hsieh, J.F., 2001. Quantifying the dietary potassium requirement of juvenile hybrid Tilapia, *Oreochromis niloticus* x *O. aureus*. British Journal of Nutrition 85, 213-218.

Shiau, S. and Hsu, 1999. Quantification of vitamin C requirement for juvenile tilapia, *Oreochromis niloticus* x *O. aureus*, with L-ascorbyl-2-monophosphate-Na and L-ascorbyl-2-monophosphate-Mg. Aquaculture 175, 317-326.

Shiau, S. and Huang, S.Y., 2001. Dietary folic acid requirement for maximal growth of juvenile Tilapia, *Oreochromis niloticus* x *O. aureus*. Fisheries Science 67, 655-659.

Shiau, S. and Hwang, J.Y., 1993. Vitamin d requirement of juvenile hybrid tilapia, *Oreochromis niloticus* x *O. aureus*. Nippon Suisan Gakkaishi 59, 553-558.

Shiau, S. and Jan, F.L., 1992. Dietary ascorbic acid requirement of juvenile tilapia, *Oreochromis niloticus* x *O. aureus*. Nippon Suisan Gakkaishi 58, 671-675.

Shiau, S. and Lin, Y., 2006. Vitamin Requirements of Tilapia-A Review, in: Cruz Suarez, L.E., Marie, D.R., Salazar, M.T., Nieto Lopez, M.G., Villarreal Cavazos, D.A. , Puello Cruz, A.C., Garcia Ortega, A.. Avances. Nutricion Acuicola VIII Simposium International de Nutricion Acuicola. 1-17 November. Universidad Autonoma de Nuevo Leon, Monterrey, Nuevo Leon, Mexico.

Shiau, S. and Lo, P.S., 2000. Dietary choline requirements of juvenile hybrid tilapia, *Oreochromis niloticus* x *O. aureus*. Journal of Nutrition 130, 100-103.

Shiau, S. and Lung, C.Q., 1993. No dietary vitamin B12 required for juvenile tilapia, *Oreochromis niloticus* x *O. aureus*. Comparitive Biochemistry and Physiology 105A, 147-150.

Shiau, S. and Su, L.W., 2003. Ferric sulfate is half effective as ferrous sulfate in meeting iron requirement for juvenile tilapia, *Oreochromis niloticus* x *O. aureus*, in: book of Abstracts, World Aquaculture, May 19-23, 2003. Salvador, Brasil. Baton Rouge, LA: World Aquaculture Society, p. 719.

Shiau, S. and Su, L.W., 2005. Juvenile tilapia, *Oreochromis niloticus* x *O. aureus* requires dietary myo-inositol for maximal growth. Aquaculture 243, 273-277.

Shiau, S. and Suen, G.S., 1992. Estimation of the niacin requirements for tilapia fed diets containing glucose or dextrin. The Journal of Nutrition 122, 2030-2036.

Shnel, N., Barak, Y.,Ezer, T., Dafni, Z. and van Rijn, J., 2002. Design and performance of a zero-discharge tilapia recirculating system. Aquacultural Engineering 26, 191-203.

Shoemaker, C.A., Klesius, P.H., and Evans, J.J., 2000. Diseases of tilapia with emphasis on economically important pathogens, in: Fitzsimmons, K., Filho, J.C. (Eds.), Tilapia aquaculture in the 21st century. Rio de Janeiro, Brazil: Panorama da Aquicultura, pp. 565-572.

Shoemaker, C.A., Klesius, P.H., and Evans, J.J., 2001. Prevalence of *Streptococcus iniae* in tilapia, hybrid striped bass and channel catfish from farms in the U.S.. American Journal of Veterinary Research 62, 174-177.

Siddiqui, A.Q., Howlander, M.S., and Adam, A.A., 1988a. Effects of dietary protein levels on growth, diet conversion and protein utilization in fry and young Nile tilapia, *Oreochromis niloticus.* Aquaculture 70, 63-70.

Siddiqui, A.Q., Al Hafedh, Y.S. and Ali, S.A., 1998b. Effect of dietary protein level on the reproductive performance of Nile tilapia, *Oreochromis niloticus*. Aquaculture Research 29, 349-358.

Sifa, L., Chenhong, L., Dey, M., and Dunham, R., 1999. Seinability of four strains of Nile tilapia, *Oreochromis niloticus*, in Chinese ponds. Aquaculture 174, 223-227.

Siraj, S.S., Smitherman, R.O., Castillo-Gallusser, S. and Dunham, R.A., 1983. Reproductive traits for three year classes of *Tilapia nilotica* and maternal effects on their progeny, in: Fishelson, L.,Yaron, Z. (Eds.), International Symposium on Tilapia in Aquaculture Tel Aviv University, pp. 210-218.

Smitherman, R.O. and Tave, D., 1987. Maintenance of genetic quality in cultured tilapia. Asian Fisheries Science 1, 75-82.

Snir, I.J., 2001. Value added tilapia products: deliberate policy or no other choice, in: Subasinghe, S., Singh, T. (Eds.), tilapia: Production, Marketing and Technological Developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia. Infofish, Kulala Lumpur, Malaysia. P. 84.

Snow, J.R. and Phelps, R.P., 1996. Hatchery Management of Warmwater Food and Sport Fish. Auburn University, Auburn, AL, pp. 102-112.

Soderberg, R.H., 2006. Culture in flowing water, in: Lim, C.E., Webster , C.D. (Eds.), Tilapia Biology, Culture, and Nutrition. New York: Haworth Press, pp. 289-312.

Soliman, A.K. and Wilson, R.P., 1992a. Water-soluble vitamin requirements of tilapia. Riboflavin requirement of blue tilapia, *Oreochromis aureus*. Aquaculture 104, 309-314.

Soliman, A.K. and Wilson, R.P., 1992b. Water-soluble vitamin requirements of tilapia. Pantothenic acid requirement of blue tilapia, *Oreochromis aureus*. Aquaculture 104, 121-126.

Souza, M.L.R., and Macedo-Viegas, E.M., 2000. Effects of filleting on processing yield of Nile tilapia, *Oreochromis niloticus*, in: Fitzsimmons, K., Filho, J.C. (Eds.), Tilapia Culture in the 21st Century. Proceedings from the fifth International Symposium on tilapia Aquaculture, Rio de Janeiro, Brazil. American Tilapia Association, Charles town, West Virginia, and ICLARM, Penang, Malaysia, pp. 451-457.

Souza, M.L.R., Marengoni, N.G., Pinto, A.A. and Cacador, W.C., 2000. Processing yield of Nile tilapia , *Oreochromis niloticus*,: head cut types and two weight classes. Acta Scientiarium 22, 701-706.

Stickney, R.R. 1986a. Principles of warmwater aquaculture. New York: John Wiley and Sons.

Stickney, R.R. 1986b. Tilapia tolerance of saline waters: a review. Progressive Fish Culturist 48, 161-167.

Stickney, R.R., McGeachin, R.B., Lewis, D.H., Marks, J., Sis, R.F., Robinson, E.H. and Wurts, W. 1984. Responses of *Tilapia aurea* to dietary vitamin C. Journal of the World Aquaculture Society 15, 179-185.

Sugita, H., Miya, C and Deguchi, Y., 1990. The vitamin B12 producing ability if intestinal bacteria isolated from tilapia and channel catfish. Nippon Suisan Gakkaishi 56, 701.

Sugg, D.W., and Chesser, R.K., 1994. Effective population sizes with multiple paternity. Genetics 137, 1147-1155.

Suresh, A.V.B. and Lin, K., 1992. Tilapia culture in saline waters: A review. Aquaculture 106, 201-226.

Suresh, A.V.B. and Lin, K., 1992b. Effect of stocking density on water quality and production of red tilapia in a recirculated water system. Aquacultural Engineering 11, 1-12.

Swingle, H.S., 1966. Biological means of increasing productivity in ponds. FAO Fisheries Report 44, 243-257.

Tave, D. 1986. Genetics for Fish Hatchery Managers. AVI Publishing, Wesport, CT, USA.

Teichert-Coddington, D. R. and Smitherman, R. O., 1988. Lack of response by *Tilapia nilotica* to mass selection for rapid early growth. Transactions of the American Fisheries Society 117, 97-300.

Teichert-Coddington, D.R. and Green, B.W., 1993.Tilapia yield improvement through maintenance of minimal oxygen concentrations in experimental grow-out ponds in Honduras. Aquaculture 118, 63-71.

Thys van den Audenaerde, D.F., 1968. Tilapia; Bibliography; Identification. Muse royal del'Afrique central (Tervuren, Belgique).

Tidwell, J., Coyle S.D., VanArnum A., Weibel C., 2000. Growth, survival, and body composition of cage-culture Nile tilapia *Oreochromis niloticus* fed pelleted and unpelleted distilled grains with solubles in polyculture with freshwater prawn *Macrobrachium rosenbergii*. Journal of the World Aquaculture Society 31, 627-631.

Toguyeni, A., Fauconneau, B, Fostier, A., Abucay, J., Mair, G. and Baroiller, J.F., 2002. Influence of sexual phenotype and genotype, and sex ratio on growth performance in Tilapia (*Oreochromis niloticus*). Aquaculture 207, 249-261.

Tonguthai, K. and Chinabut, S., 1997. Diseases of tilapia, in: Egna, H., Boyd, C.E. (Eds.), Dynamics of Pond Aquaculture. Boca Raton, FL: Lewis Publishers, pp. 263-287.

Trewavas, E., 1982. Tilapias: taxonomy and speciation, in: Pullin, R.S.V., Lowe-McConnell, R.H. (Eds.), The biology and culture of tilapias. Manila Philippines: ICLARM Conference Proceedings Number 7, pp. 3-13.

Trewavas, E., 1983. Tilapiine fishes of the genera *Sarotherodon, Oreochromis* and *Danakilia.* Itahaca, NY: University Press.

Ulloa, J., 1995. Nutrición de tilapia. In: 1er Simposio Centroamericano Sobre El Cultivo de Tilapia, in: Gálvez, N., Günther, J., Porras, A., Pérez, H., Zurburg, W. (Eds), San José, Costa Rica, pp. 33–53.

United States Department of Agriculture, 2005. Census of Aquaculture. http://www.agcensus.usda.gov/Publications/2002/Aquaculture/index.asp

United States Department of Commerce Bureau of Census. 2010. http://www.ers.usda.gov/data/aquaculture/Tables/Tilapia_V_Yearly.pdf

United States Department of Commerce National Oceanic and Atmospheric Administration, 2010. Aquaculture Program. Aquaculture in the United States. http://aquaculture.noaa.gov/us/welcome.html

United States Department of Agriculture Foreign Agricultural Service, 2005. International Trade Report.

United States Food and Drug Administration, 2010. Approved Drugs for the use in aquaculture. http://www.fda.gov/AnimalVeterinary/DevelopmentApprovalProcess/Aquaculture/ucm132954.htm

Uraiwan, S. 1988. Direct and indirect responses to selection for age at first maturation of *Oreochromis niloticus*, in: Pullin, R.S.V., Bhukaswan, T., Tonguthai, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. Department of Fisheries, Thailand and International Center for Living Aquatic Resources Management, Bangkok, pp. 295-300.

Uraiwan, S. and Phanitchai, V., 1986. A study of strain selection of *Tilapia nilotica.* Aquaculture 57, 376-377.

Van Gorder, S., 1998. Tilapia in recirculating aquaculture systems. Aquaculture 24, 21-23.

Vromant, N., Nam C.Q., Frans, O., 2002. Growth performance of *Barbodes gonionotus* in intensively cultivated rice fields. Aquaculture 212, 167-178.

Watanabe, T., Satoh, S. and Takeuchi, T., 1988. Availability of minerals in fish meal to fish. Asian Fisheries Science 1, 75-195.

Watanabe, W.O., Losordo, T.M., Fitzsimmons, K. and Hanley, F., 2002. Tilapia Production Systems in the Americas: Technological Advances, Trends, and Challenges. Reviews in Fisheries Science 10, 465-498.

Waples, R.S., 1998. Separating the wheat from the chaff: patterns of genetic differentiation in high gene flow species. Journal of Heredity 89, 438-450.

Welcomme, R.L., 1967. The relationship between fecundity and fertility in the mouthbrooding cichlid fish *Tilapia leucostricta*. Journal of Zoology (London) 151, 453–468.

Wheaton, F.W., Hochheimer, J.N., Kaiser, G.E., Krones, M.J., Libey, G.S., Easter, C., 1994. Nitrification filter principles, in: Timmons, M.B., Losordo, T.S. (Eds.), Aquaculture Water Reuse Systems: Engineering Design and Management. Amsterdam: Elsevier, Chapter 4.

Winfree, R. A. and Stickney, R. R., 1981. Effects of dietary protein and energy on growth, feed conversion efficiency and body composition of *Tilapia aurea.* Journal of Nutrition 111, 1001-1012.

Wohlfarth, G.W. and Hulata, G., 1981. Applied genetics of tilapias. ICLARM Studies and Reviews 6 (2nd edition). International Center for Living Aquatic Resources Management, Manila, Philippines.

WorldFish Center, 2003. A selected bibliography on tilapia (Pisces: Cichlidae): a list of documents available in the WorldFish Center Library, The WorldFish Center, Ian R. Smith Memorial Library and Documentation Center,

Xia, D.Q. 2000. The current status of tilapia culture and prospects in China. Scientific Fish Farming 5, 1-2.

Yanbo, W., Wenju, Z. and Zirong X., 2006. Acute toxicity of nitrite on tilapia, *Oreochromis Niloticus*, at different external chloride concentrations. Fish Physiology and Biochemistry 1, 49-54.

Yashouv, A. and Helevy, A., 1971. Studies on comparative growth of *Tilapia aurea* and *T. vulcani* in experimental ponds at Dor. Fisheries and Fish Breeding in Israel 6, 7-21.

Zouros, E. and Pogson, G.H., 1994. The present status of the relationship between heterozygosity and heterosis, in: Beaumont, A.R. (Ed.), Genetics & Evolution of Aquatic Organisms. Chapman & Hall, London, pp. 134-146.

CHAPTER 2

EVALUATION OF PRODUCTION CHARATERISTICS OF FOUR STRAINS OF NILE TILAPIA *Oreochromis niloticus* AND A RED VARIETY IN AN INDOOR INTENSIVE RECIRCULATING SYSTEM

Abstract

Intensive recirculating aquaculture is becoming a more widely practiced form of aquaculture. Through their tolerance to crowding, acceptance of a wide range of foods, feed conversion efficiency, rapid growth rate, and ease of reproduction, tilapias are highly suited for production in these systems. A trial was conducted at Auburn University to compare production characteristics of four populations of *O. niloticus* using two domesticated strains (Egypt and Ivory Coast) and two less domesticated strains (Sagana and Lake Victoria). In addition, a red variety of tilapia (Santa Fe) was also evaluated.

The different strains were compared under intensive conditions in an indoor recirculating system at a mean (±SD) temperature (^{o}C) of 27.1 ± 2.8 and fed commercially available diets for 203 days. Initial mean body weights (g/fish) at stocking ranged from 4.6 ± 0.27 (Sagana) to 6.0 ± 0.2g (Egypt) ($P < 0.001$). Initial mean (±SD) stocking density (kg/m^3) ranged from 2.1 ± 0.1 (Sagana) to 2.7 ±0.1 (Egypt) ($P = 0.003$). Mean (±SD) weight gain (g/fish) and individual harvest weight (g/fish) was greatest for the Ivory Coast strain, 48 ± 1.0 and 53.4 ± 1.4, respectfully. Mean (±SD) percent (%) survival was the greatest for the Egypt line 97.5 ± 5.5. Mean (±SD) feed conversion ratios during this period ranged from 1.4 ± 0.1 to 1.6 ± 0.1.

Introduction

Tilapia culture is based on a limited number of species and few founding populations for a given species. These founding populations were used in pond culture settings and have been further selected to such production settings. However, not all tilapia culture is pond-based.

Intensive recirculating aquaculture is becoming a more widely practiced form of aquaculture. Site-independency relative to the quantity, quality and temperature of water, cost of land or other parameters outside of acceptable ranges, market-vicinity and reduction of environmental impact has been the main drive for tilapia recirculating systems (Shnel et al., 2002). The typical recirculating or "closed" system consists of settling tanks (for solids removal), biological and/or mechanical filters (for ammonia removal), ultra-violet light (for sterilization) and aeration (blowers, air compressors or compressed oxygen) (El-Sayed, 2006). A full description of this system has been reviewed by a number of authors (Mires and Anjioni, 1997; Losordo et al., 1999; Muir et al., 2000).

Tilapias are highly suited for production in recirculating aquaculture systems (RAS), showing high tolerance to crowding, ready acceptance of a wide range of foods, good feed conversion efficiency, rapid growth rate, and ease of reproduction (Kidd and Hallerman, 2002). Indoor RAS address a number of concerns to the aquaculture industry. They generally provide a higher degree of environmental control, require less water and less land area per kg of fish, can be located in relatively close proximity to markets to reduce transportation costs and stress and mortalities during live transport, and can increase bio-security (Watanabe et al., 2002). RAS have the potential to mitigate much of the environmental impact of fish production systems by reducing the volume of water discharged and focusing a higher strength waste into a point source (Losordo, 1997).

Strain comparison is a complex topic considering the issues of fish size, age, genotype-environment interactions and various domestication selection pressures. Uraiwan (1988) confirmed that a genetic relationship exists between growth rate, age and size at maturity in Nile tilapia. Some investigations have suggested that genotype-environmental interactions are probably minor among strains and selected lines (Eknath et al., 1993; Uraiwan and Phanitchai, 1986; Macaranas, 1997) but are more of an influence among comparisons of species and hybrids (Smitherman and Dunham, 1985). However, Romana-Eguia and Doyle (1992) observed a significant genotype-environmental interaction in the response of three *O. niloticus* strains to poor nutrition. Li et al. (2002) reported difference among Nile strains of tilapia relative to cold tolerance. Macaranas and Fujio (1990) reported on comparison of genetic changes in broodstocks of five cultured fish species and showed them to be influenced by the intensity of selection pressure and/or history of culture. Osure and Phelps (2006) reported differences in relative fecundity (seed/g female), percent females that spawned and incubation success among four strains of Nile tilapia with varying degrees of domestication. However, they reported no difference in primary and secondary nursery production relative to growth or survival.

Since aquaculture species represent isolated breeding populations with distinct genetic attributes, the first step of selection is to characterize available strains or lines and subsequently select one or more that excel in certain areas from which to form a base population for improvement. This is of particular significance in tilapia due to the frequent use of small founder populations and accelerated inbreeding among isolated production stocks (Lutz, 2006). Temperature, salinity, fecundity, feeding habits and growth have all been evaluated under a variety of conditions, but results have often been somewhat variable among studies evaluating the same species. Such variability may be explained in part by differences among particular

strains within species, and this phenomenon certainly appears to exist in tilapia (Eknath et al., 1993).

The primary focus of this study was to compare production characteristics of four strains of *O. niloticus* and a red variety (Santa Fe) in an indoor intensive recirculating system with the primary objective to successfully over-winter tilapia fingerlings for later outdoor production. In addition, comparisons on production characteristics relative to the domestication status of the four populations of *O. niloticus* were also performed. Domestication herein refers to longevity of culture history, especially within indoor/overwintering conditions. The four populations of *O. niloticus* included two established domesticated lines (Egypt and Ivory Coast) and two less domesticated lines (Sagana and Lake Victoria).

Materials and Methods

Four strains of Nile tilapia and a red variety of varying geographical origins and domestication histories were compared in an intensive recirculating aquaculture system. The Ivory Coast strain was established at Auburn in 1974 from a batch of 100 fish from Fortaleza, Brazil (Lovshin and De Silva, 1975). Ancestors of the strain (100–200 fish) were introduced to Fortaleza from Bouake, Ivory Coast in 1971 (Lovshin and De Silva, 1975). The stock at Bouake, Ivory Coast, was from the tributaries of the Niger and Lake Volta (Trewavas, 1983). The Egypt strain of Nile tilapia was collected from the Ismailia canal of the Nile River, about 75 km northeast of Cairo, with 20 males and 66 females introduced to Auburn University in May, 1982 (Khater, 1985). Sagana and Lake Victoria strains were introduced to Auburn University in March 2002 from Kenya (Osure and Phelps, 2006). The Sagana strain originated from Lake Turkana. It was introduced to Baobab farm, Kenya in the early 1980s (Trewavas, 1983) and then

introduced to Sagana Fisheries Research Station, Sagana, Kenya in 1994 (Osure and Phelps, 2006). This subspecies was classified by Trewavas (1983) as *Oreochromis niloticus vulcani*. The Auburn University stock was founded from 35 fingerlings with an average weight of 45 g (Osure and Phelps, 2006). Fish of the Lake Victoria strain were the first generation offspring of brood stock introduced to the Sagana Fisheries Research Station four months prior from Lake Victoria. The Auburn population was established from 240 fry (age = 3 weeks). The Auburn University stock of the red variety (Santa Fe strain) was established from 136 individuals. They were obtained in August 2000 from Colombia, South America. Ivory Coast and Egypt strains are highly domesticated strains having remained as closed populations for 36 and 28 years, respectfully. The Sagana and Lake Victoria strains have a shorter history of domestication.

All five populations were compared in an indoor recirculating system from October 10, 2006 through May 1, 2007 (203 days) in a 674 m^3 greenhouse. A set of 15 cylindrical fiberglass tanks (1.1 m^3 each) connected to a common bio-filter were used in this evaluation. De-chlorinated (sodium thiosulfate) tap-water with a hardness of 40 mg/L and alkalinity of 40 mg/L was the source of water. The water flow rate was managed at 1.7 L/min/tank to give an exchange rate of 102 L/hr. A natural gas heater/blower was used to manage air temperature above 16 ^oC in the greenhouse. The water was heated with three Clepco (model # 9220-A R-24) bayonet type electrical heaters with thermostat set to 28^oC. Aeration was provided by a Sweetwater (1 h.p.) regenerative air blower at an average of 900 cm^3/sec /tank. Filtration of the system was accomplished with a vortex-type suspended solids settler (1900 L) and a Model BBF-XS Aquaculture Systems Technologies, L.L.C. bubble bead filter (50.15 m^3 of bead media), which provided 186 m^2 of surface area. According to the listed equipment specifications, the bead filter could process up to 3.5 kg of feed per day. The maximum daily

load of feed imposed on the system was 2.97 kg. The system was back-flushed on an "as needed" basis. This was based on increasing organic loads in filter which increased system pressure at or near maximum (15 psi) recommended levels and/or high (≥ 1.0 mg/L) levels of nitrite or unionized ammonia.

Alkalinity, pH, alkalinity, nitrite and un-ionized ammonia were measured daily with Mardel (Virbac Corporation) 5 in 1 test strips. The water quality results of the test strips were verified using a LaMotte AQ-2 freshwater aquaculture test kit. Temperature and dissolved oxygen was measured periodically (once/week) throughout the culture period with a Yellow Springs Instruments (YSI) model 55 dissolved oxygen meter. All water quality samples were consistently collected from the output of the bio-filter that was representative of the entire system.

The tanks were stocked with mixed sex tilapia (5-6 g) at an initial standing crop of 2.1 to 2.7 kg/m^3 (500 fish/tank). There were three replicates per treatment. The fish were fed to satiation once daily. Satiation, as defined herein, was offering an initial 25% of the daily ration. If all feed was consumed, an additional 25% of the daily ration was offered. This continued until feeding response ceased. Daily feed ration was adjusted bi-weekly (and corrected based on monthly samples) based on feeding recommendations relative to individual total length of individual fish (Popma and Green, 1990). The two types of feed used were a commercially available 45% protein floating pellet (2.3 mm) (AquaMax, Purina Mills) and 36% protein floating pellet (3 mm) (Cargill). Fish weights were sampled at stocking (10/10/2006), 41 days (11/20/2003), 125 days (2/12/2007) and at 203 days (5/1/2007). The size of feed used was adjusted based on fish size.

The following parameters were evaluated: mean (±SD) initial number (#/m^3), individual intial weight (g/fish), initial standing crop (kg/m^3), harvest weights (g/fish), weight gain (g/fish), final standing crop (kg/m^3), survival (%) and feed conversion ratio (FCR). FCR was calculated as the ratio of the sum of the amount of feed fed (kg) to the sum of the fish harvested (kg). In addition, grand means (± SD) were calculated and compared for all previously mentioned production characteristics between the domesticated (Egypt and Ivory Coast) strains and less domesticated strains (Sagana and Lake Victoria) and between Nile strains and the red variety. Furthermore, all significant parameters were modeled to identify relationships.

Statistical analyses were performed using SAS (SAS Institute Inc., SAS 9.1.3, Cary, NC: SAS Institute Inc., 2000-2004.). Data from experiments were analyzed using the analysis of variance (ANOVA) F-test to determine if there were significant differences ($P \leq 0.05$) among mean parameters. When assumptions for ANOVA were violated, the Kruskal-Wallis nonparametric test of ranked sums was used. Fisher's least significant difference (LSD), Tukey's honest significant difference (HSD), Scheffe's and Bonferroni-Dunn tests were used as the post-hoc tests to determine differences among the strains. Linear regression analysis was used to model significant differences.

Results

Means ± standard deviation (SD) for each strain of fish and their initial number, individual initial weights, initial standing crop, individual harvest weight, weight gain, survival, feed conversion ratios and final standing crop are presented in Table 1. All significant differences were modeled to identify relationships and are addressed in the discussion section

(Table 2). All initial mean body weights (g/fish) at stocking were not significantly different (5.6 ± 0.4g to 6.0 ± 0.2g) with the exception of the Sagana strain (4.6 ± 0.27) ($P \leq 0.001$).

Final mean weight at harvest and weight gains differed significantly by strain ($P = 0.01$ and $P = 0.008$ respectfully). Ivory Coast had the largest (53.4 ± 1.4g) mean weight at harvest and Sagana had the smallest (39.9 ± 5.6g) ($P = 0.01$). The Ivory Coast strain showed the greatest mean (±SD) weight gain (48 ± 1.0g) and Sagana the least (35.3 ± 5.5g) ($P = 0.008$).

The Egypt strain showed the highest mean percent survival (97.5 ± 5.5%) while the Ivory Coast showed the lowest (81.7 ± 6.8%). There were no differences by strain in mean final standing crop (kg/m^3) and FCR. Final standing crop ranged from 16 ± 2.4 to 20 ± 1.3 kg/m^3 days. FCR at harvest ranged from 1.4 ± 0.2 to 1.6 ± 2.0.

Grand means ± standard deviation (SD) for the Nile strains and red variety of fish and their initial number, individual initial weights, individual harvest weight, weight gain, survival, feed conversion ratios and standing crops are presented in Table 3. The only significant ($P = 0.046$) difference between all Nile (1.4 ± 0.1) strains and the red (1.6 ± 0.1) variety was in FCR.

Grand means ± standard deviation (SD) for the domestication status of fish and their initial number, individual initial weights, initial standing crop, individual harvest weight, weight gain, survival, feed conversion ratios and final standing crop are presented in Table 4. All significant differences were modeled to identify relationships and are addressed in the discussion section (Table 5). Significant differences were found among all parameters except for initial number, survival and FCR. Initial individual weights (g/fish) were found to be larger for the domesticated lines (5.9 ± 0.9) compared to the less domesticated lines (5.1 ± 0.9) ($P < 0.0001$). Initial standing crop (kg/m^3) was larger for the domesticated lines (2.7 ± 0.03) compared to the less domesticated lines (2.3 ± 0.3) ($P = 0.008$). Individual harvest weight (g/fish) was larger for

the domesticated lines (49.8 ± 12.3) compared to the less domesticated lines (40.6 ± 6.8) ($P < 0.0001$). Weight gain (g/fish) was larger for the domesticated lines (43.0 ± 13.1) compared to the less domesticated lines (35.5 ± 6.5) ($P < 0.0001$). Final standing crop (kg/m^3) was larger for the domesticated lines (19.8 ± 1.4) compared to the less domesticated lines (16.8 ± 61.7) ($P = 0.007$).

Means (±SD) for temperature (27.1 ± 2.8 ^oC), dissolved oxygen (4.6 ± 0.71 mg/L), pH (6.6 ± 0.43), alkalinity (88.9 ± 15.27 mg/L), un-ionized ammonia (0.05 ± 0.11 mg/L) and nitrite (0.79 ± 0.76 mg/L) are presented in Table 6.

Reproduction was noted at harvest in the tanks and bio-filter sump. However, it was not measured due to the probability of egg/fry translocation and inability to differentiate among strains.

Discussion

In the United States, intensive culture of tilapia is becoming more widespread (Watanabe et al. 2002; El-Sayed, 2006). However, most of the strains of tilapia being cultured were developed for pond production applications. The primary objective of this culture method was to successfully over-winter tilapia fingerlings for later outdoor production.

Final standing crops from the indoor system ranged from 16 ± 2.4 to 20 ± 1.3 kg/m^3. These were lower than yields (30 kg/m^3) reported by DeLong et al. (2009) and lower than results from oxygenated recirculating systems reported by Schroeder and Serfling (1989) of 65 to 70 kg/m^3/year and by Losordo (1997) of 75 kg/m^3/120 days. Muir et al. (2000) reported in a growth period of 240 d in recirculating individual weight gain from 5 to 350 g (1.44 g/d). Rakocy (1989) reported the growth of Nile tilapia from 5 to 50 g in 28-30^oC water was 0.75 g/d.

These are much higher than the mean individual daily growth rate of 0.20 ± 0.02 g/d calculated herein. Rakocy (1989) fed (5-10 % biomass/day/5-18 g fish; 3-5% biomass/day/18-75 g fish) and aerated (5-7.5 mg/L) at higher rates than was practiced in this study (feeding = 2.5% biomass/day; dissolved oxygen = 4.6 ± 0.71 mg/L). In addition, both of the systems described by Muir (2000) and Rakocy (1989) utilized an all male stock. The system used herein had the production goal of overwintering of mixed-sex broodstock.

All parameters demonstrating significant differences were modeled using ANOVA to determine relationships (Table 2). A positive correlation was observed between mean stocking weight and mean individual harvest weight ($R^2 = 0.31$; P= 0.03) (Figure 1) and final standing crop ($R^2 = 0.34$; P= 0.02) (Figure 2). Individual harvest weight and final standing crop increased with an increase in initial weight. Among the strains evaluated, the Ivory Coast appeared to out-perform all others. Even with a relatively low survival (which was not correlated with other production characteristics), this strain made up the difference in yield with its superior gain. Upon initial observation the Sagana strain appeared to have the worst performance. However, after consideration of this strain having the lowest stocking weight and the positive correlation of this parameter with harvest weight and final standing crop, this strain having the worst performance cannot be inferred.

Upon initial observation the more domesticated lines (Egypt and Ivory Coast) appeared to out-perform the less domesticated strains (Sagana and Lake Victoria) relative to weight gain ($P < 0.001$) and final standing crop ($P = 0.007$) . However, considering the positive correlations between initial weight and harvest weight ($R^2 = 0.44$) ($P = 0.02$) (Figure 3), gain ($R^2 = 0.31$) ($P = 0.04$) (Figure 4) and final standing crop ($R^2 = 0.46$) ($P = 0.02$) (Figure 5) a positive production advantage relative to domestication status cannot be inferred.

The typical tilapia production cycle at Auburn is 7.5 months indoors and 4.5 months outdoors. What is unique about the domesticated (Ivory Coast and Egypt) strains is that they have been cultured for more than 25 years in intensive over-wintering systems. However, these strains showed no special advantage over the less domesticated (Sagana and Lake Victoria) strains that had been cultured in over-wintering systems for much less time. No difference was observed in survival ($P = 0.637$) or FCR ($P = 0.583$) for the domesticated ($89.6 \pm 10.3\%$; 1.5 ± 0.08) versus the less domesticated ($91.9 \pm 5.0\%$; 1.4 ± 0.11) strains respectfully.

The idea that domesticated strains suffer from inbreeding depression (Tave and Smitherman, 1980; Hulata et al,. 1986; Teichert-Coddington and Smitherman, 1988; Eknath et al., 1993; Brummett, 2004) may apply to these results. It might be argued that both domestication status groups were handled throughout their culture under management strategies that prevented or reduced inbreeding depression. Smitherman and Tave (1987) reported that maintenance of an effective breeding number of 100-150 broodfish sustains 99% of genetic variability and reduces inbreeding depression. Another stance is that both groups were mishandled at some point in their lineage and all suffered inbreeding depression. Nonetheless, there was no difference in production characteristics among domestication status observed under these culture conditions.

When evaluated collectively, under these intensive culture conditions, the Nile strains demonstrated a production advantage over the Red variety. Higher standing crops among the collective Nile strains were attributed to increased initial weight and higher survival. Trends of *O. niloticus* outperforming Red varieties have been previously reported (Matricia, 1989; Hussain et. al., 2000; Lovshin, 2000; Ng and Hanim, 2007). However, these works were conducted outdoors and suffered high mortality mostly attributed to bird predation. Reproduction was

noticed in the culture system herein, though was not quantified. Lovshin et al. (1990) reported significant differences in male tilapia growth when stocked with all male, 2.5% female and 5.0% females relative to competition for growth from offspring that were detectable at four months of culture. Furthermore, Lovshin et al. (1990) also reported no difference in total yield among all previously described treatments. Therefore, this suggests that reproduction in these experiments would not over-ride any potential strain differences relative to total final standing crop.

Conclusion

Among the Nile strains evaluated under the intensive indoor culture conditions of this research station, no one strain demonstrated a distinct production advantage. The superior production characteristics demonstrated by the more domesticated over the less domesticated lines of Nile tilapia were attributed to larger stocking weight and higher initial standing crop. Therefore, no difference in domestication status was observed. When evaluated collectively, the Nile strains demonstrated no production advantages over the Red variety.

Table 1
Mean (±SD) for initial number (#/m^3), initial weight (g/fish), initial standing crop (kg/m^3) harvest weight (g/fish), survival (%), feed conversion ratio (FCR) and final standing crop (kg/m^3) of four strains of Nile tilapia (*Oreochromis niloticus*) and a red variety (Santa Fe) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.

Parameter Mean	**Egypt (n=3)**	**Ivory Coast (n=3)**	**Lake Victoria (n=3)**	**Sagana (n=3)**	**Red (n=3)**	**P-Value**
initial number (#/m^3)	494.3 (± 9.8)	500 (± 0.0)	500 (± 0.0)	500 (± 0.0)	500 (± 0.0)	0.452
initial weight (g/fish)	6.0 (± 0.2)^{a}	6.0 (± 0.0)^{a}	5.7 (± 0.3)^{a}	4.6 (± 0.3)^{b}	5.6 (± 0.4)^{a}	0.000
initial standing crop (kg/m^3)	2.7 (± 0.1)^{a}	2.7 (± 0.0)^{ab}	2.6 (± 0.1)^{ab}	2.1 (± 0.1)^{c}	2.4 (± 0.3)^{b}	0.003
harvest weight (g/fish)	47.0 (± 4.2)^{a}	53.4 (± 1.4)^{b}	42.5 (± 0.9)^{ac}	39.9 (± 5.6)^{c}	42.3 (± 4.2)^{ac}	0.010
weight gain (g/fish)	41.6 (± 3.5)^{a}	48 (± 1.0)^{b}	35.7 (± 2.4)^{a}	35.3 (± 5.5)^{a}	37.0 (± 4.4)^{a}	0.009
survival (%)	97.5 (± 5.5)^{a}	81.7 (± 6.8)^{b}	94.7 (± 3.9)^{ab}	89.1(± 4.8)^{ab}	88.3 (± 3.4)^{ab}	0.025
FCR	1.4 (± 0.1)	1.5 (± 0.1)	1.5 (± 0.1)	1.4 (± 0.2)	1.6 (± 0.1)	0.231
final standing crop (kg/m^3)	20.0 (± 1.3)	19.6 (± 1.7)	17.6 (±0.4)	16.0 (± 2.4)	16.8 (± 2.0)	0.059

Table 2
Regression analysis modeled for the independent variables of initial weight (g/fish), initial standing crop (kg/m^3), survival (%) and weight gain (g/fish) to the dependent variables of harvest weight (g/fish), final standing crop (kg/m^3), weight gain (g/fish), survival (%) and FCR and of four strains of Nile tilapia (*Oreochromis niloticus*) and a red variety (Santa Fe) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.

Dependent variable	**Independent variable**			
	initial weight	initial standing crop	survival	weight gain
harvest weight	$R^2 = 0.31$, $P = 0.03$	$P = 0.43$	$P = 0.15$	$R^2 = 0.99$, $P < 0.0001$
final standing crop	$R^2 = 0.34$, $P = 0.02$	$P = 0.06$	$P = 0.57$	$R^2 = 0.69$, $P = 0.0001$
weight gain	$P = 0.07$	$P = 0.10$	$P = 0.17$	.
survival	$P = 0.96$	$P = 0.47$	.	$P = 0.17$

Table 3
Mean (±SD) for initial number (# fish/tank), initial weight (g/fish), initial standing crop (kg/m^3) harvest weight (g/fish), weight gain (g/fish), survival (%), FCR, and final standing crop (kg/m^3) of all Nile (*Oreochromis niloticus*) tilapia strains compared the red (Santa Fe) tilapia variety from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once /day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.

Parameter Mean	**Nile Strains (n= 12)**	**Red Variety (n= 3)**	**P-Value**
initial number	498.6 ± 4.9	500 ± 0.0	0.635
initial weight	5.5 ± 1.0	5.6 ± 0.7	0.606
initial standing crop	2.5 ± 0.3	2.4 ± 0.3	0.658
harvest weight	45.2 ± 10.9	42.3 ± 6.7	0.193
weight gain	39.2 ± 10.9	36.8 ± 6.9	0.578
survival	90.8 ± 7.8	88.3 ± 3.4	0.604
FCR	1.4 ± 0.1	1.6 ± 0.1	0.046
final standing crop	18.3 ± 2.2	16.8 ± 2.0	0.308

Table 4
Mean (±SD) for initial number (#/m^3), initial weight (g/fish), initial standing crop (kg/m^3) harvest weight (g/fish), survival (%), feed conversion ratio (FCR) and final standing crop (kg/m^3) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.

Parameter Mean	**Domesticated (n= 6)**	**Less Domesticated (n= 6)**	**P-Value**
initial number	497.2 ± 6.9	500 ± 0.0	0.341
initial weight	5.9 ± 0.9	5.1 ± 0.9	0.000
initial standing crop	2.7 ± 0.03	2.3 ± 0.3	0.008
harvest weight	49.8 ± 12.3	40.6 ± 6.8	0.000
weight gain	43.0 ± 13.1	35.5 ± 6.5	0.000
survival	89.6 ± 10.3	91.9 ± 5.0	0.637
FCR	1.5 ± 0.08	1.4 ± 0.11	0.583
final standing crop	19.8 ± 1.4	16.8 ± 1.7	0.007

Table 5
Regression analysis modeled for the independent variables of initial weight (g/fish), initial standing crop (kg/m^3), survival (%) and weight gain (g/fish) to the dependent variables of harvest weight (g/fish), weight gain (g/fish) and survival (%), FCR and final standing crop (kg/m^3) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once /day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.

Dependent variable	**Independent variable**			
	initial weight	initial standing crop	survival	weight gain
harvest weight	$R^2 = 0.44$, $P = 0.02$	$R^2 = 0.45$, $P = 0.02$	$P = 0.14$	$R^2 = 0.99$, $P < 0.001$
weight gain	$R^2 = 0.31$,$P = 0.04$	$P = 0.06$	$P = 0.13$	.
survival	$P = 0.92$	$P = 0.35$	.	$P = 0.13$
FCR	$P = 0.25$	$P = 0.68$	$P = 0.39$	$P = 0.97$
final standing crop	$R^2 = 0.46$, $P = 0.02$	$R^2 = 0.25$, $P = 0.05$	$P = 0.76$	$R^2 = 0.66$, $P = 0.001$

Table 6
Management level values and means (± SD) for temperature (^{o}C), dissolved oxygen (mg/L), pH, total alkalinity (mg/L), Nitrite (mg/L), unionized ammonia (mg/L) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.

Parameter	**Management Level**	**Mean**
temperature	26-30	27.1 ± 2.8
dissolved oxygen	5.0	4.6 ± 0.71
pH	6.5 – 7.5	6.6 ± 0.43
alkalinity	80-100	88.9 ± 15.27
nitrite	managed below 1.0	0.79 ± 0.76
NH_3	managed below 1.0	0.05 ± 0.11

Figure 1
Relationship between mean intial weight (g/fish) and mean harvest weight (g/fish) of four strains of Nile tilapia (*Oreochromis niloticus*) and a red variety (Santa Fe) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days. (R^2 = 0.31) (P = 0.03)

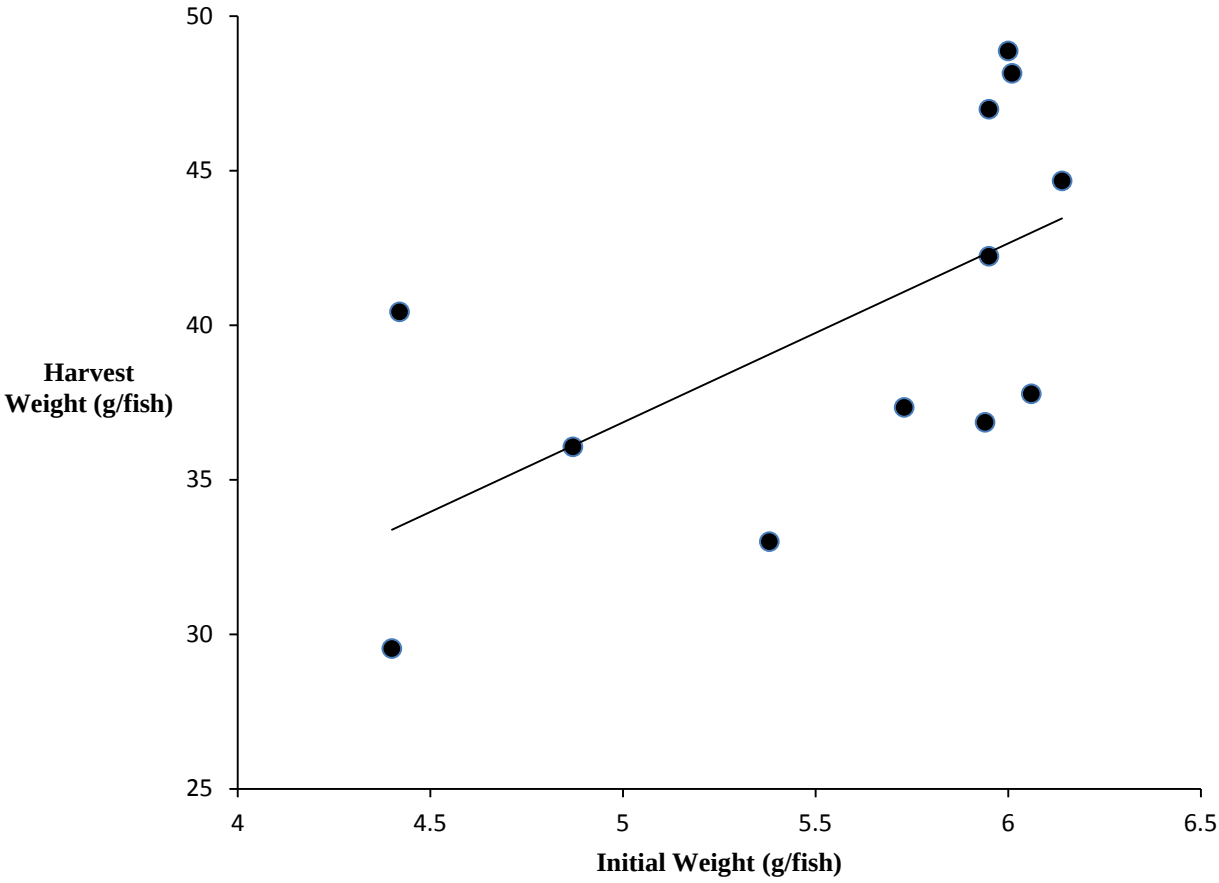


Figure 2
Relationship between mean intial weight (g) and mean final standing crop (kg/m^3) of four strains of Nile tilapia (*Oreochromis niloticus*) and a red variety (Santa Fe) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days. (R^2 = 0.34) (P = 0.02)

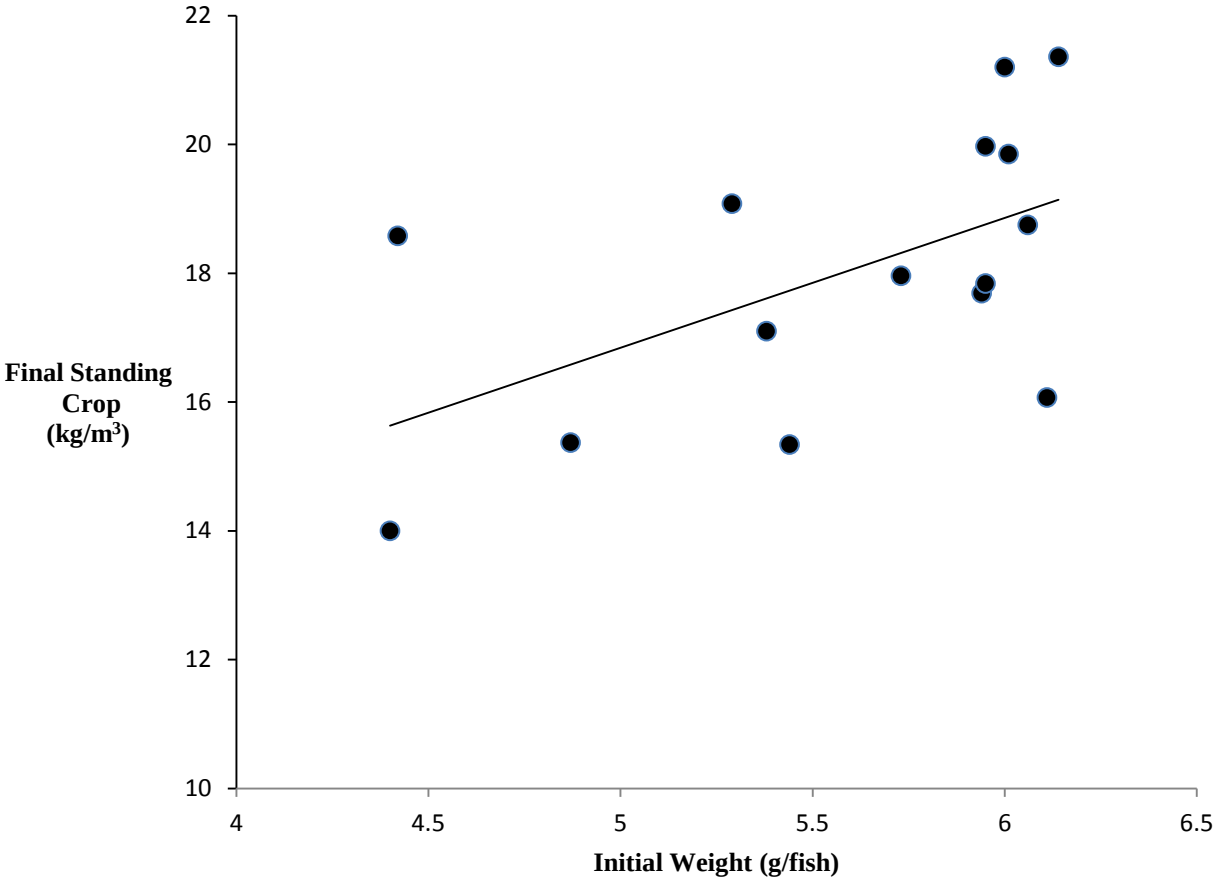


Figure 3
Relationship between mean initial weight (g/fish) and mean harvest weight (g/fish) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.
(R^2 = 0.44)(P = 0.02)

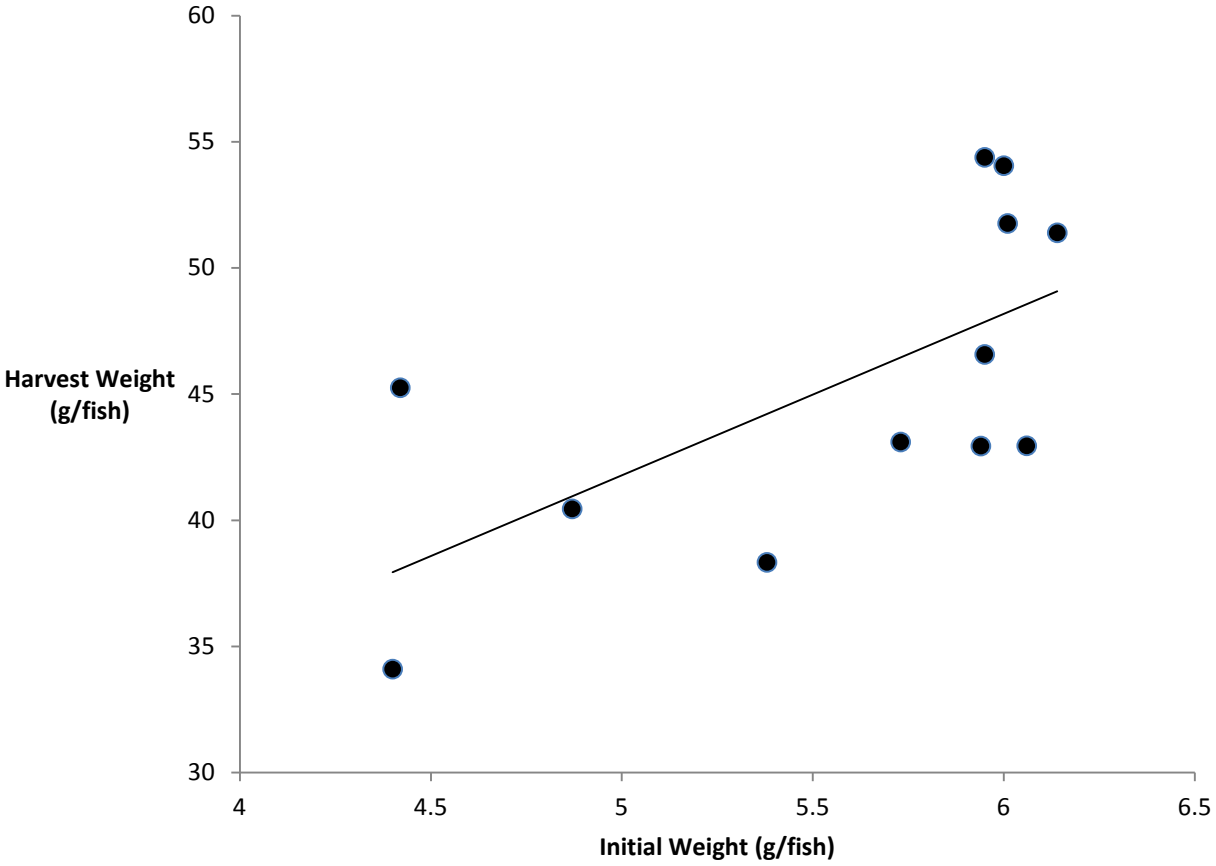


Figure 4
Relationship between mean intial weight (g/fish) and mean weight gain (g/fish) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.
(R^2 = 0.99) (P < 0.0001)

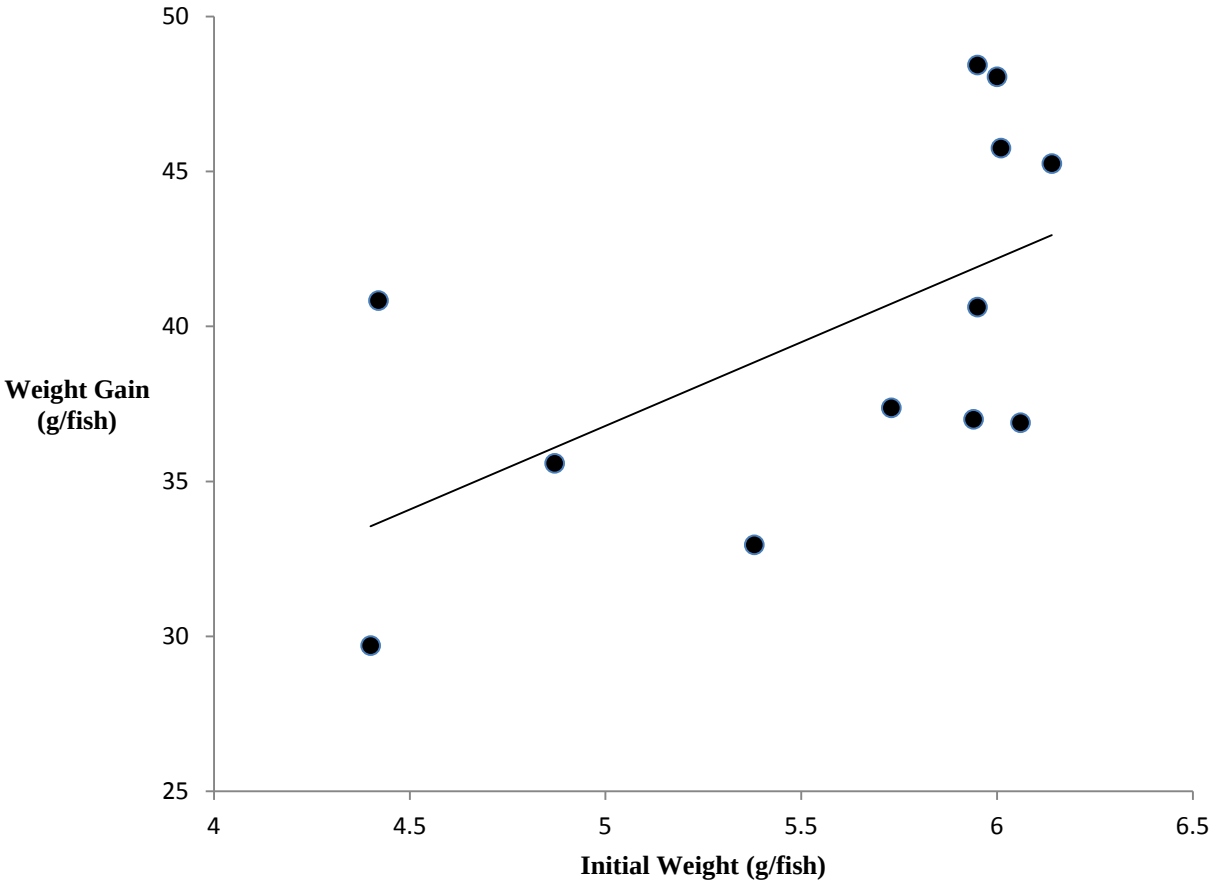


Figure 5
Relationship between mean initial weight (g/fish) and mean final standing crop (kg/m^3) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days.
(R^2 = 0.46) (P = 0.02)

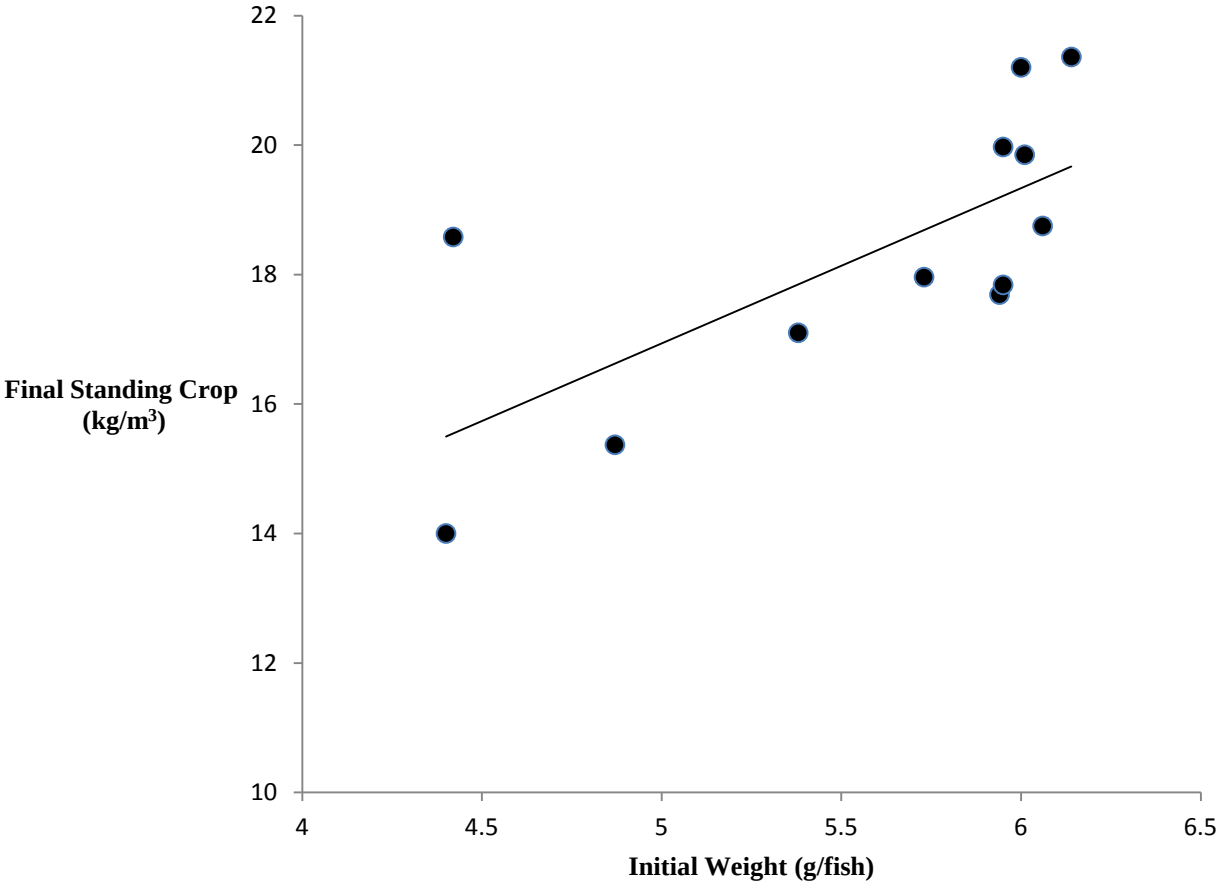


Figure 6
Relationship between mean intial standing crop (kg/m^3) and mean harvest weight (g/fish) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days. (R^2 = 0.45) (P = 0.02)

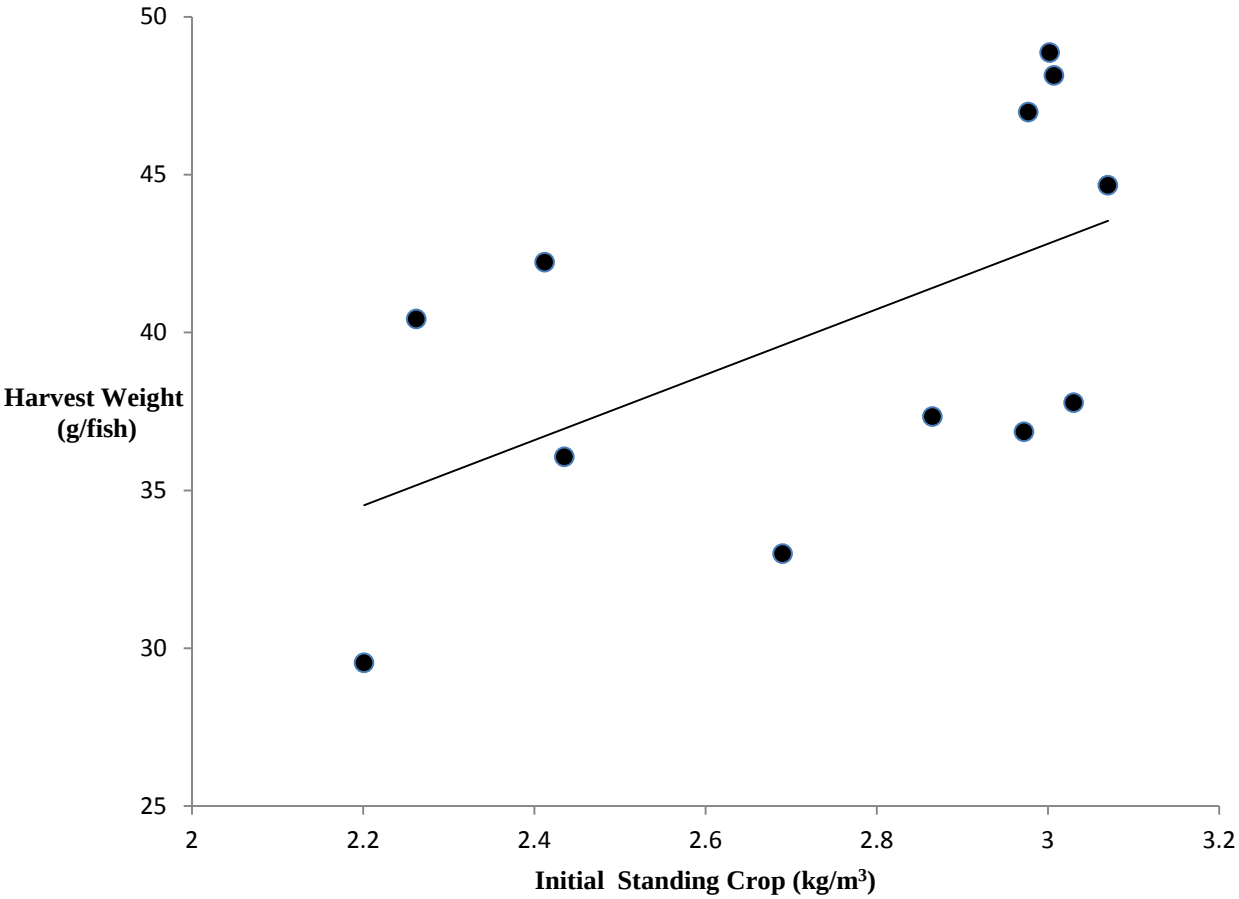
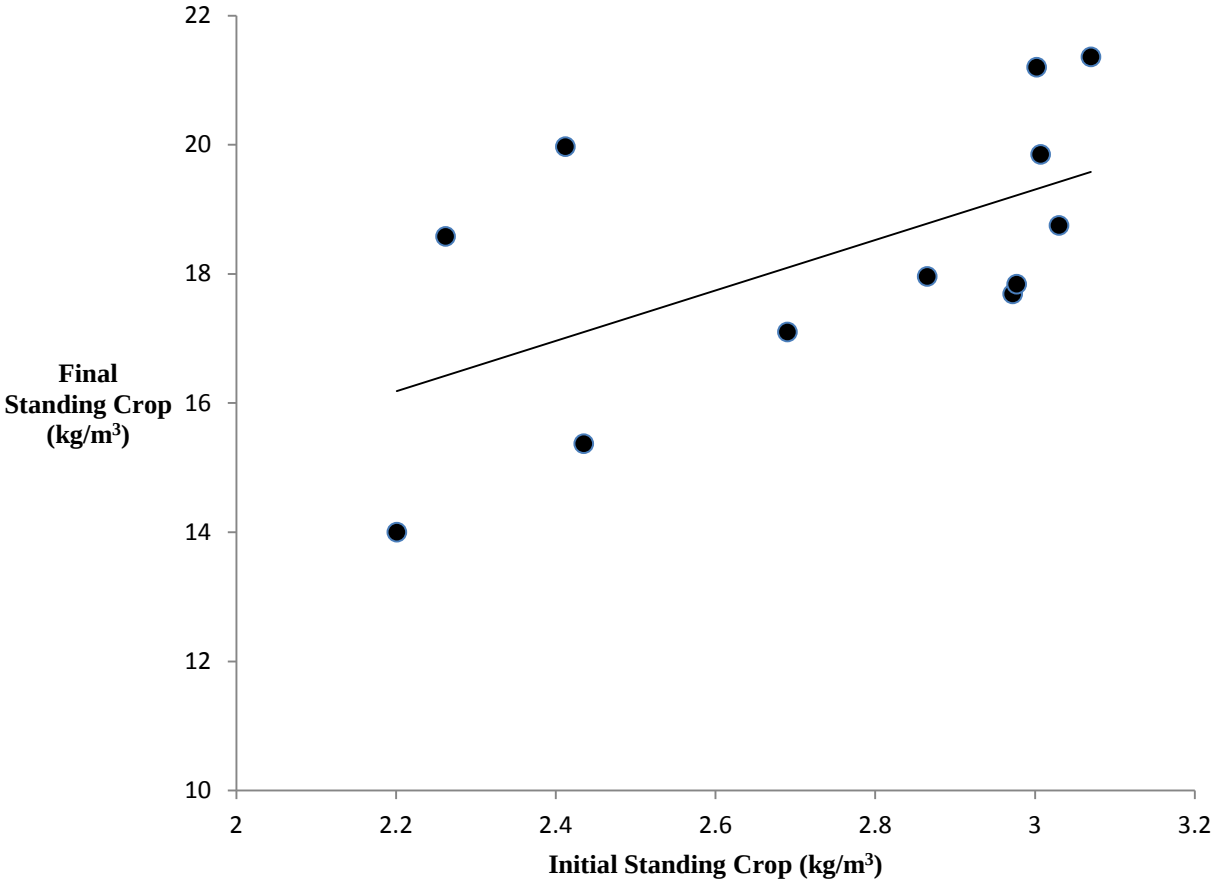


Figure 7
Relationship between mean initial standing crop (kg/m^3) and mean final standing crop (kg/m^3) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana) from a recirculating indoor production system where tilapia were stocked at 2.1 to 2.7 kg/m^3 and fed once/day to satiation commercially available diets of 45% protein and later 36% protein floating pellets for 203 days. (R^2 = 0.25) (P = 0.05)



References

Avtalion, R.R. and Shlapobersky, M., 1994. A whirling viral disease of tilapia larvae. Israeli Journal of Aquaculture (Bamidgeh) 46, 102–104.

Baras, E., Mélard, C., 1997. Individual growth patterns of juvenile Nile tilapia, *Oreochromis niloticus*. Emergence and dynamics of sexual growth dimorphism, in: Fitzsimmons, K. (Ed.), Tilapia Aquaculture, Proceedings from the Fourth International Symposium on Tilapia in Aquaculture 9–12 May 1997, Orlando, Florida, USA. NRAES. Volume 106. pp. 169–177.

Baerends, G. P., and Baerends-van Roon, J. M., 1950. An introduction to the study of the ethology of cichlid fishes. Behavior 1, 1-242.

Beardmore, J.A., G.C. Mair and Lewis, R.I., 1997. Biodiversity in aquatic ecosystems in relation to aquaculture. Aquaculture Research 28, 829-839.

Beardmore, J.A. and Shami, S.A., 1979. Heterozygosity and the optimum phenotype under stabilizing selection. Aquilo Series Zoologica, 100-110.

Bestari, Njoman, 2004. An Impact Evaluation of Genetically Improved Farmed Tilapia and Their Dissemination in Developing Countries. Operations Evaluations Department. Asian National Bank. IES:Reeg 2004-20.

Clement, S. and Lovell, R.T., 1994. Comparison of processing yields and nutrient composition of cultured Nile tilapia, *Oreochromis niloticus*, and channel catfish, *Ictalurus punctatus*. Aquaculture 119, 299-310.

Dan, N.C. and Little, D.C, 2000. The culture performance of monosex and mixed sex new season and over-wintered fry in two strains on Nile tilapia, *Oreochromis niloticus*, in northern Vietnam. Aquaculture 184, 221-231.

Danzmann, R.G., Ferguson, M.M. and Allendorf, F.W., 1988. Heterozygosity and comparison of fitness in a strain of rainbow trout. Biological Journal of the Linnean Society 33, 285-304.

DeLong, D.P., Losordo, T.M. and Rakocy, J.E., 2009. Tank Culture of Tilapia. Southern Regional Aquaculture Center. Publication Number 282.

Eknath, A.E., Tayamen, M.M., Palada-de Vera, M.S., Danting, J.C. and Reyes, R.A., 1993. Genetic improvement of farmed tilapias: the growth performance of eight strains of *Oreochromis niloticus* tested in different farm environments. Aquaculture 111, 171-188.

El-Sayed, Abdel-Fattah, 2006. Tilapia Culture. CABI Publishing, Cambridge, MA, USA.

Gajardo, G. and Beardmore, J.A., 1989. Ability to switch reproductive mode in *Artemia* is related to maternal heterozygosity. Marine Ecolgy Progess Series 55, 191-195.

Gentili, M.R. and Beaumont, A.R. , 1988. Environmental stress, heterozygosity and growth rate in *Mytilus edulis*. Journal of Experimental Marine Biology and Ecology 120, 145-153.

Hulata, G., Wohlfarth, G. W. and Halevy, A., 1986. Mass selection for growth rate in the Nile Tilapia, *Oreochromis niloticus*. Aquaculture 57, 177-184.

Hussain, M.G., Kohinoor, A.H.M., Islam, M.S.; Hossain, M.A.; Dey, M.M. and Mazid, M.A., 2000. Growth and production performances of gift strain of Nile tilapia, *Oreochromis niloticus* in ponds and cages under different farming conditions in Bangladesh. Journal of Tropical Aquaculture 15, 273-280.

Khater, A.A.E. ,1985. Identification and comparison of three Tilapia nilotica strains for selected aquacultural traits. Auburn University, Alabama, USA, Ph.D. dissertation.

Khaw, H.L., Ponzoni, R.W. and Danting, M.C., 2008. Estimation of genetic change in the GIFT strain of Nile tilapia, *Oreochromis niloticus*, by comparing contemporary progeny produced by males born in 1991 or in 2003. Aquaculture 275, 64-69.

Kidd, M. and Hallerman, E., 2002. Growth performance of genetically male and selectively bred tilapia in recirculating aquaculture systems. Proceedings of the 4th International Conference on Recirculating Aquaculture.

Li, S.F., Li, C.H., Dey, M., and Dunham, R., 1999. Seinability of four strains of Nile tilapia, *Oreochromis niloticus*, in Chinese ponds. Aquaculture 174, 223-227.

Li, S.F., Li, C., Dey, M., Gagalac, F. and Dunham, R., 2002. Cold tolerance of three strains of Nile tilapia, *Oreochromis niloticus*, in China. Aquaculture 213, 123-129.

Longalong, F.M., Eknath, A.E. and Bentsen, H.B., 1999. Response to bidirectional selection for frequency of early maturing females for Nile tilapia, *Oreochromis niloticus*. Aquaculture. Volume 178. Pages 13-25.

Losordo, T.M. 1997. Tilapia culture in intensive recirculating systems. In: Tilapia Aquaculture in the Americas. Volume 1, in: Costa-Pierce, B.A. and Rakocy, J.E. (Eds.), Baton Rouge, Louisiana: The World Aquaculture Society, pp. 185–211.

Losordo, T., Masser, M. and Rakocy, J., 1999. Recirculating aquaculture tank production systems a review of component options. Southern Regional Aquaculture Center. Publication Number 453.

Lovshin, L.L., De Silva, A.B., 1975. Culture of monosex and hybrid tilapia. FAO/CIFA/75/SR9. Symposium on Aquaculture in Africa. Accra, Ghana, p. 16.

Lovshin, L.L., De Silva, A.B., Carneiro-Sobrinho and Melo, F.R., 1990. Effects of *Oreochromis niloticus* females on the growth and yield of male hybrids,*O. niloticus* female x *O. hornorum* male, cultured in earthen ponds. Aquaculture 88, 55-60.

Lovshin, Leonard L., 2000. Criteria for selecting Nile tilapia and red tilapia for culture, in: Fitzsimmons, K. and Carvalho Filho, J., (Eds.), Tilapia Aquaculture in the 21st Century Proceedings from the Fifth International Symposium on Tilapia in Aquaculture Volume 1, Ministry of Agriculture, Rio de Janeiro, Brazil, pp. 49–57.

Lutz, Greg C., 2006. Recent directions in genetics, in: Lim, C.E. and Webster, C.D. (Eds.), Tilapia Biology, Culture and Nutrition. Food Products Press an Imprint of Haworth Press Inc. New York. pp. 139-167.

Macaranas, J.M. and Fujio, Y., 1990. Strain differences in cultured fish – Isozymes and performance traits as indicators. Aquaculture 85, 69-82.

Matricia, T, Talbot, A.J. and Doyle, R.W., 1989. Instantaneous growth rate of tilapia genotypes in undisturbed aquaculture systems "Red" and "grey" morphs in Indonesia. Aquaculture 77, 295-306.

Mazid, M.A. Hussain, M.G. and Alam, M.J., 1996. Proceedings of a workshop on current status and future strategy for dissemination of genetically improved farmed tilapia in Bangladesh. Fisheries Research Institute, Mymensingh, Bangladesh.

Mires, D. and Anjioni, C., 1997. Technical and economic comparative evaluation of two intensive closed water-cylced culture systems for tilapias in Israel, in: Fitzsimmons, K.(Ed.), Proceedings from the fourth international symposium on tilapia in aquaculture. Northeast Regional Agricultural Engineering Service, Ithaca, New York, pp. 416-425.

Muir, J., J. van Rijn, and Hargreaves, J., 2000. Production in intensive and recycle systems, in: Beveridge, M. C and McAndrews, B. J. (Eds.), Tilapias: biology and exploitation. Kluwer, London, pp. 405–445.

Ng, W. and Hanim, R., 2007. Performance of genetically improved Nile tilapia compared with red hybrid tilapia fed diets containing two protein levels. Aquaculture Research 38, 965-972.

Osure, G.O. and Phelps, R.P., 2006. Evaluation of reproductive performance and early growth of four strains of Nile tilapia, *Oreochromis niloticus*, with different histories of domestication. Aquaculture 253, 485-494.

Penman, D.J. and McAndrew, B.J., 2000. Genetics for the management and improvement of cultured tilapias, in: Beveridge, M.C.M. and McAndrew, B.J. (Eds.), Tilapias: Biology and Exploitation. Fisheries Series 25 Kluwer, Dordrecht, The Netherlands, pp. 227-226.

Popma, T.J. and Green, B.W. 1990. Sex reversal of tilapia in earthen ponds. Alabama Research and Development Series. Number 35. International Center for Aquaculture, Alabama Experiment Station, Auburn University, Alabama.

Rakocy, J. E. 1989. Tank culture of tilapia. Southern Regional Aquaculture Center, Publication 282, College Station, Texas.

Ridha, Mohammad T., 2006. Comparative study of growth performance of three strains of Nile tilapia, *Oreochromis niloticus* at two stocking densities. Aquaculture Research 37, 172-179.

Romana-Eguia, M.R.R. and Doyle, R.W., 1992. Genotype-environment interaction in the response of three strains of Nile tilapia to poor nutrition. Aquaculture 108, 1-12.

Rutten, M., Bovenhuis, H. and Komen, H., 2004. Modeling fillet traits based on body measurements in three Nile tilapia strains, *Oreochromis niloticus*. Aquaculture 231, 113-122.

Schroeder, G.S. and Serfling, S., 1989. High-yield aquaculture using low-cost feed and waste recycling methods. American Journal of Alternative Agriculture 4, 71–74.

Shnel, N., Barak, Y.,Ezer, T., Dafni, Z. and van Rijn, J., 2002. Design and performance of a zero-discharge tilapia recirculating system. Aquacultural Engineering 26, 191-203.

Smitherman, R.O. and Tave, D., 1987. Maintenance of genetic quality in cultured tilapia. Asian Fisheries Science 1, 75-82.

Teichert-Coddington, D. R. and Smitherman, R. O., 1988. Lack of response by *Tilapia nilotica* to mass selection for rapid early growth. Transactions of the American Fisheries Society 117, 297-300.

Trewavas, E., 1983. Tilapiine fishes of the genera *Sarotherodon, Oreochromis* and *Danakilia.* Cornell Itahaca, NY: University Press.

Uraiwan, S. 1988. Direct and indirect responses to selection for age at first maturation of *Oreochromis niloticus*, in: Pullin, R.S.V., Bhukaswan, T., Tonguthai, K.,Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. Department of Fisheries, Thailand and International Center for Living Aquatic Resources Management, Bangkok, pp. 295-300.

Uraiwan, S. and Phanitchai, V., 1986. A study of strain selection of *Tilapia nilotica.* Aquaculture 57, 376-377.

Zouros, E. and Pogson, G.H., 1994. The present status of the relationship between heterozygosity and heterosis, in: Beaumont, A.R. (Ed.), Genetics & Evolution of Aquatic Organisms. Chapman & Hall, London, pp. 134-146.

CHAPTER 3

EVALUATION OF PRODUCTION CHARATERISTICS OF FOUR STRAINS OF NILE TILAPIA *Oreochromis niloticus* AND A RED VARIETY IN AN OUTDOOR INTENSIVE STATIC SYSTEM

Abstract

The wide cultured range of *Oreochromis niloticus* offers the possibility of genetic diversity within the species and variation among populations as to their suitability for culture. But only a few populations have been evaluated as to their culture potential and less in head to head comparisons. A trial was conducted at Auburn University, Auburn, AL, USA to compare production characteristics of four populations of *O. niloticus* using two domesticated strains (Egypt and Ivory Coast) and two less domesticated strains (Sagana and Lake Victoria). In addition, a red variety of tilapia (Santa Fe) was also evaluated.

All strains were cultured under high density conditions in an outdoor static system at a mean (±SD) temperature (^{o}C) of 27.1 ± 2.8 and fed a commercial 36% protein floating feed for a 120-day culture period. Males (100.4 ± 5.2 g) were hand sexed (mean hand sexing error = 1.8 ± 1.2%) and stocked at the density of 3 fish/m^2. All Nile strains out-performed the Red variety relative to survival. No distinct production advantage was noticed in strain or domestication status among Nile strains. Final standing crops of 9,508 ± 396 to 14,438 ± 779 kg/ha were achieved. Percent of final standing crop as reproduction averaged 15.3 ± 7.5 % among Nile strains. Mean (±SD) percent (%) survival was the greatest for the Egypt strain (97.5 ± 5.5) and

least for the Red strain (78.8 ±13.9). Mean (±SD) feed conversions ranged from 1.3 ± 0.1 (Sagana strain) to 1.9 ± 0.08 (Red strain). Final standing crop (kg/ha) ranged from 9,508 ± 396 (Red strain) to 14,438 ±779 (Sagana strain).

Introduction

Tilapias are endemic to tropical freshwater in Africa, Jordan, and Israel where more than 70 species have been identified (Philippart and Ruwet, 1982; Macintosh and Little, 1995; McAndrew, 2000). However, relatively few species are commercially important, and even fewer are of aquacultural significance (Shelton and Popma, 2006).

The majority of production of Nile tilapia is based on six initial sources: Ivory Coast, Ghana, Egypt-Manzala, Egypt-Ismailia, Sudan-Nile and Lake George Uganda. These founding stocks were commonly established from a limited number of wild fish. Most of these introductions were made in the late 1960s and early 1970s and have been redistributed throughout the world (Khater and Smitherman, 1988; Pullin and Capili, 1988). The small size of many founding populations and lack of subsequent introductions have resulted in a high incidence of inbred stocks.

A challenge when establishing new fish species for use in aquaculture is to begin with adequate genetic diversity. The genetics of cultured tilapia have routinely been poorly managed and has given rise to at least three forms of genetic concerns (Kocher et al., 1998). First is the loss of pure species through mismanagement of inter-specific hybridization (McAndrew, 1993), a technique used to produce all-male fry which have a higher growth rate in production systems (Hickling, 1960; Hulata et al., 1983). A second problem is high levels of inbreeding depression. During domestication, unintentional selection of traits that increase survival and reproductive

success can be negatively correlated with growth, seinability, dress-out or other commercially important characteristics (Doyle, 1983; Tave, 1986). Furthermore, domestication selection pressures may produce a genotype-environmental effect. This is where species are selected for production traits that have evolved under a specific set of culture conditions (e.g. temperature, water quality, quality of nutrient inputs, etc). Therefore, fish that perform well under one set of culture conditions may not be well-suited to another (McIntyre and Blanc, 1973; Dunham et al., 1990; Wohlfarth et al., 1983; Matricia et al., 1992; Romana-Equia and Doyle, 1992). Finally, there is evidence for contamination of genetically improved strains by introgression from feral species (Macaranas et al., 1986).

Since aquaculture species represent isolated breeding populations with distinct genetic attributes, the first step of selection is to characterize available strains or lines and subsequently select one or more that excel in certain areas from which to form a base population for improvement. This is of particular significance in tilapia due to the frequent use of small founder populations and accelerated inbreeding among isolated production stocks (Lutz, 2006). Temperature, salinity tolerance, fecundity, feeding habits and growth potential have been evaluated under a variety of conditions, but results have often been somewhat variable among studies evaluating the same species (Hulata et al. 1986; Teichert-Coddington and Smitherman, 1988). Such variability may be explained in part by differences among particular strains within species, and this phenomenon certainly appears to exist in tilapias (Eknath et al., 1993).

Selective breeding of tilapias was reviewed by Penman and McAndrew (2000). They concluded that the low heritability for growth observed in many trials were an outcome of the low genetic variation typical of the cultured stocks used. The genetically improved farmed tilapia (GIFT) program based on a synthetic base population from wild

and domestic stocks of Nile tilapia resulted in improved growth and survival (Longalong et al., 1999; Khaw et. al., 2008; Ridha, 2006). The program aimed to produce high performing stocks that could be further selected by national centers in countries wishing to improve tilapia culture. The benefits to farmers from the program varied by country; in Bangladesh GIFT compared very favorably to many local strains (Mazid et al,. 1996) but differences were much less evident in Vietnam and Thailand where local strains performed well (Dan and Little 2000). In addition, there was evidence that the GIFT strains were less tolerant to cooler climates (Li et. al., 2002).

Strain comparison is a complex topic considering the issues of fish size, age, genotype-environment interactions and various domestication selection pressures. Uraiwan (1988) confirmed that a genetic relationship exists between growth rate, age and size at maturity in Nile tilapia. Some investigations have suggested that genotype-environmental interactions are probably minor among strains and selected lines (Eknath et al., 1993; Uraiwan and Phanitchai, 1986; Macaranas, 1997) but are more of an influence among comparisons of species and hybrids (Smitherman and Dunham, 1985). However, Romana-Eguia and Doyle (1992) observed a significant genotype-environmental interaction in the response of three *O. niloticus* strains to poor nutrition. Li et al. (2002) reported differences among Nile strains of tilapia relative to cold tolerance. Macaranas and Fujio (1990) reported on comparison of genetic changes in broodstocks of five cultured fish species and showed them to be influenced by the intensity of selection pressure and/or history of culture. Osure and Phelps (2006) reported differences in relative fecundity (seed/g female), percent females that spawned and incubation success among four strains of Nile tilapia with varying degrees of domestication. However, they reported no difference in primary and secondary nursery production relative to growth or survival.

Intensive commercial tilapia production requires a fish that grows rapidly, is an efficient feed converter, has high survival and tolerates poor water quality. The following study compared production characteristics of four strains of *O. niloticus* and a red variety (Santa Fe) under intensive production conditions.

Materials and Methods

Four strains of Nile tilapia and a red variety of varying geographical origins and domestication histories were compared. Ivory Coast strain was established at Auburn in 1974 from a batch of 100 fish from Fortaleza, Brazil (Lovshin and De Silva, 1975). Ancestors of the strain (100–200 fish) were introduced to Fortaleza from Bouake, Ivory Coast in 1971 (Lovshin and De Silva, 1975). The stock at Bouake, Ivory Coast, was from the tributaries of the Niger and Lake Volta (Trewavas, 1983). The Egypt strain of Nile tilapia was collected from the Ismailia canal of the Nile River, about 75 km northeast of Cairo, with 20 males and 66 females introduced to Auburn University in May, 1982 (Khater, 1985). Sagana and Lake Victoria strains were introduced to Auburn University in March 2002 from Kenya (Osure and Phelps, 2006). The Sagana strain originated from Lake Turkana. It was introduced to Baobab farm, Kenya in the early 1980's and then introduced to Sagana Fisheries Research Station, Sagana Kenya in 1994 (Osure and Phelps, 2006). This subspecies was classified by Trewavas (1983) as *Oreochromis niloticus vulcani*. The Auburn University stock was founded from 35 fingerlings with an average weight of 45 g (Osure and Phelps, 2006). Fish of the Lake Victoria strain were the first generation offspring of brood stock introduced to the Sagana Fisheries Research Station 4 months prior from Lake Victoria. The Auburn population was established from 240 fry (age = 3

weeks). The Auburn University stock of the red variety (Santa Fe strain) was established from 136 individuals. They were obtained in August, 2000 from Colombia, South America. Ivory Coast and Egypt strains were considered highly domesticated strains while the Sagana and Lake Victoria were considered less domesticated for comparison of production characteristics herein.

The grow-out culture trial was conducted in 20 outdoor 12 m^3 (mean depth = 0.6 m) concrete tanks from May 30, 2007 through September 27, 2007. Initially, there were four replicates per treatment. However, due to mechanical aeration failure and subsequent heavy mortality, one of the Egypt replicates was omitted from data. The water source was filtered (~250 µm mesh) surface water harvested from a forested watershed and held in an 8.1 ha reservoir. Agricultural limestone was added (13.6 kg) to each of the replicates at the beginning of the experiment. Water was exchanged (50% by volume) in each tank when concentrations of unionized ammonia were high (>1 mg/L) or nitrite levels were (>1 mg/L). Continuous aeration was provided by a Sweetwater (1 h.p.) regenerative air blower at an average of 3000 cm^3/sec/tank using 3 m of a generic brand of 2.5 cm diameter diffuser hose.

Dissolved oxygen was sampled once daily between 0600 h to 0700 h. Temperature and pH were sampled once/day between 1500 h to 1600 h. Total ammonia nitrogen (TAN), un-ionized ammonia and nitrite were sampled weekly at 1500 h to 1600 h. Hardness, alkalinity, TAN, chloride and nitrite were further sampled on an "as needed" basis with a LaMotte AQ-2 freshwater aquaculture chemical titration test kit. Un-ionized ammonia was calculated based on the equation: $NH_3 = 1/ (10^{pka} - pH + 1)$, where pka = 0.0901827 + 2729.92/T, and where T = is the temperature in degrees Kelvin, (C^o + 273.2) (Thurston et al., 1974). Oxygen and temperature were measured with an YSI model 55 dissolved oxygen meter. The pH was measured with a Hach HQ 40d.

The tanks were stocked with hand-sexed male tilapia (100.4 ± 5.2 g) at a 3 fish/m^2 density. There were four replicates per treatment. The fish were fed twice daily to satiation with a commercial 36% protein floating pellet (3 mm) (Cargill). Satiation defined herein was feeding as much as the fish would eat for a period up to but no longer than 15 minutes. An average number of 40 fish per tank were sampled once per month by seining (0.63 cm mesh) and mean weights determined to the nearest 0.1 g.

During the study, females were noticed in the first monthly sample. Reproduction was first noticed in most tanks during the first month at feeding and confirmed at the first monthly sampling. The females were counted, weighed and removed when found during each monthly sampling and at harvest. The total weight of reproduction was recorded at harvest. Length and weight data were collected at harvest on twenty tilapia fingerlings from each tank where reproduction occurred. Largemouth bass fingerlings (8 to 13 cmTL) were stocked on June 29, 2007 at the rate of 5 per tank to help control reproduction. Total count and weights of the bass were recorded at harvest.

The following parameters were evaluated: mean initial and harvest weights (g/fish), weight gain (g/fish), growth (g/day), final standing crop (kg/m^2), survival (%), feed conversion ratio (FCR), weight (g) of females and reproduction harvested (kg) and its percentage of total harvest. Final standing crop was calculated as the sum of the weight of males harvested (kg/m^2), females harvested (kg/m^2) and fry/fingerling harvested (kg/m^2). Survival was calculated as the number of fish stocked divided by the number of adult fish at harvest (which included the number of females that were removed during monthly sampling) multiplied by 100. FCR was calculated as the ratio of the sum of the amount of feed fed (kg) to the sum of the fish (males, females and fry/fingerlings) harvested (kg). Fish were harvested by repeated (3 to 4) seining

and a final draining. The number and weight (kg) of fish harvested were recorded per seining. Average fish weight at harvest was calculated excluding the reproduction. At harvest, a sample (n=25 fish /strain) of male fish with similar size range (416 ± 22 g) was used to calculate condition factors (K) with the following formula: K = {(total weight (g) / total length^3 (cm)) x 100} (Fulton, 1911; Hassan et al., 2008).

Statistical analyses were performed using SAS (SAS Institute Inc., SAS 9.1.3, Cary, NC: SAS Institute Inc., 2000-2004.). Data from experiments were analyzed using the analysis of variance (ANOVA) F-test to determine if there were significant differences (P=0.05) among treatments. When assumptions for ANOVA were violated, the Kruskal-Wallis nonparametric test of ranked sums was used. Fisher's least significant difference (LSD), Tukey's honest significant difference (HSD), Scheffe's and Bonferroni-Dunn tests were used as the post-hoc tests to determine strain differences. Linear regression analysis was used to model significant differences.

Results

Mean (±SD) initial weights (g/fish) of Ivory Coast (100.0 ± 1.7g), Sagana (101.5 ± 4.7g), Red (94 ± 5.4g) and Lake Victoria (97.8 ± 2.2g) were not significantly different (P = 0.24), the Egypt strain were significantly larger (110.5 ± 2.4g) (P ≤ 0.0001) (Table 1). Mean male growth (g/day) was not significantly different among strains (P = 0.68). At harvest, males differed (P = 0.02) in mean (±SD) individual weight among treatments and ranged from 365 ± 37g for Lake Victoria to 473 ± 30g for Sagana (Table 1). Mean (±SD) male weight (g) gain was greatest for the Sagana strain 369 ± 28 and lowest for the Lake Victoria strain 268 ± 38. Mean (±SD) final standing crops (kg/ha) at harvest were similar for the Nile strains (Range = 12,914 ± 1129 kg/ha

to 14,438 ± 779 kg/ha) with the Red tilapia having a lower final standing crop (9,508 ± 396 kg/ha) (Table 1). Mean condition of strains differed ($P \leq 0.0001$) and ranged from 1.8 ± 0.12 for Egypt strain to 2.1 ± 0.23 for the Red strain (Table 1).

Mean FCR for the tilapia strains were not significantly different ($P = 0.145$) and ranged from 1.3 ± 0.18 for Ivory Coast to 1.9 ± 0.08 for the Red strain (Table 2). The maximum daily amount of feed offered was 249.5 kg/ha. Mean (±SD) total percent yield by male weight ranged from 77.0 ± 9.5% for Ivory Coast to 99.0 ± 1.0% for Red ($P = 0.006$) (Table 1). The Egypt strain had the highest mean (±SD) percent (%) survival (98.3 ± 1.7%) and the Red strain had the lowest (78.8 ± 13.9%) ($P = 0.025$) (Table 2). No major observed mortality events occurred during the study frame.

The average error in hand-sexing males was 1.8 ± 1.2%. Females were removed when found at each sampling period (Table 3). They were first noticed at the 60 day sample. The total number of females that were harvested at 60 days was similar ($P = 0.96$) among treatments and ranged from 0.25 ± 0.5 per treatment for Egypt to 0.5 ± 0.58 per treatment for all other strains. Total mean weight (g) of females harvested at 60 days were similar ($P = 0.89$) among treatments and ranged from 102.7 ± 0.0g for Egypt to 160.2 ± 25.5g for Red. Females were found and removed at the 90 day sample. The total number of females that were harvested at 90 days was similar ($P = 0.44$) among treatments and ranged from 0.25 ± 0.5 per treatment for Lake Victoria to 0.0 per treatment for all other strains. The average weight (g) of the female harvested at 90 days from the Lake Victoria treatment was 138.0 g. At harvest, the remaining number of females ranged from 0.25 ± 0.5 per treatment for Egypt, Red and Sagana to 1.5 ± 0.58 per treatment ($P = 0.053$). The grand total number of females harvested ranged from 0.5 ± 0.58 per treatment for Egypt to 2.25 ± 0.96 per treatment for Lake Victoria ($P = 0.026$). The percent

female contribution to final standing crop (kg/ha) were similar (P = 0.372) among treatments and ranged from 0.29 ± 0.26% for Egypt to 1.0 ± 0.99% for Red (Table 2).

Reproduction was first noticed at approximately 30 days after stocking. Mean (±SD) individual lengths (mm) of reproduction at harvest were not significantly different (P = 0.97) among treatments and ranged from 12.0 ± 1.3 mm for Lake Victoria to 12.9 ± 3.6 mm for Sagana (Table 4). It should be noted that there was observed reproduction in the Red replicates during monthly sampling efforts but none were present harvest. Mean (±SD) individual weight (g) of reproduction at harvest was similar (P = 0.92) among Nile strains and ranged from 33.2 ± 12.3g for Lake Victoria to 45.3 ± 35.8 g for Sagana. Final standing crop as reproduction (kg/ha) among all strains was significantly different (P = 0.017) and ranged from 0.0 for Red to 3,062 ± 1,447 for Ivory Coast (Table 1). No significant difference (P = 0.2) in final standing crop as reproduction (kg/ha) among Nile strains were observed and ranged from 879 ± 1,153 for Sagana to 3,062 ± 1,447 for Ivory Coast (Table 1).

Largemouth bass fingerlings (~3-4g) were stocked in all tanks at 0.25/m^2 on day 30. No differences were found among the mean (±SD) parameters of largemouth bass (LMB) at harvest (Table 5). The final mean density (#/m^2) of largemouth bass was similar (P = 0.08) ranging from 0.05 ± 0.03 for Sagana to 0.15 ± 0.08 for Lake Victoria. Individual weights of largemouth bass at harvest were similar (P = 0.96) among treatments and ranged from 11.5 ± 19.3 g for Egypt to 13.9 ± 3.8 g for Sagana. Total weights of largemouth bass at harvest were not significantly different (P = 0.57) among treatments and ranged from 13.9 ± 3.8g for Sagana to 38.0 ± 18.8g for Red. The contributions of largemouth bass were not included in the calculation of final standing crop. Bass final standing crops (kg/ha) ranged from the highest in the Red strain (25.8 ± 11.7) to the lowest in the Sagana strain (3.4 ± 4.1).

Measured water quality parameters were not significantly different among treatments (Table 6). Mean (±SD) afternoon (1500 h – 1600 h) temperatures were similar among treatments (P = 0.58) and ranged from 30.3 ± 0.1 ^{o}C for Egypt to 30.4 ± 0.1 ^{o}C for Lake Victoria. Mean morning (0500h – 0600 h) dissolved oxygen were not significantly different among treatments (P = 0.99) and ranged from 4.1 ± 0.3 mg/L for Lake Victoria to 4.2 ± 0.4 mg/L for Egypt. Mean frequency of morning (a.m.) dissolved oxygen levels below 2.0 mg/L was similar among treatments (P = 0.81) and ranged from 6.1 ± 4.4% for Lake Victoria and 9.3 ± 5.6% for Ivory Coast. Mean afternoon pH among treatments were similar (P= 0.57) and ranged from 8.0 ± 0.1 for Lake Victoria to 8.2 ± 0.1 for Sagana. Mean afternoon pH levels above 10 were similar among treatments (P = 0.95) and ranged from 4.6 ± 5.3% for Ivory Coast and Lake Victoria to 6.8 ± 8.7% for Sagana . Mean alkalinity among treatments were similar (P = 0.96) and ranged from 73.0 ± 4.8 mg/L for Egypt to 86.3 ± 4.0 mg/L from Ivory Coast. Mean hardness among treatments were similar (P= 0.46) and ranged from 66.5 ± 3.4 mg/L for Red to 76.3 ± 16.1 mg/L for Sagana. Mean chloride was similar among strains (P = 0.21) and ranged from 17.6 ± 1.6 mg/L for Egypt to 21.5 ± 3.3 mg/L for Red. Mean nitrite values were similar among strains (P = 0.48) and ranged from 0.5 ± 0.2 mg/L for Ivory Coast to 0.9 ± 0.3 mg/L for Sagana.

Mean un-ionized ammonia values were not significantly different among treatments (P = 0.31) and ranged from 0.1 ± 0.1 mg/L for Red to 0.4 ± 0.4 mg/L for Ivory Coast. Mean frequency of un-ionized ammonia concentration ≥ 1.0 were similar among treatments (P = 0.68) and ranged from 0.0 ± 0.0% for Red to 5.6 ± 6.4 % for Lake Victoria. Mean of the frequency of water exchange were similar among treatments (P = 0.23) and ranged from 0.8 ± 0.3 times / month for Ivory Coast to 1.1 ± 0.4 times / month for Sagana.

When concrete tanks with vertical sides were used, an average of 41 ± 8.8% were captured in the first seining. After three seinings, an average of 96.8 ± 0.05% was captured. Mean percent seinability were similar among all strains (P= 0.098) (Table 1). The Ivory Coast strain had the highest percent seinability with 52 ± 8.8% of the initial stock caught in the first seine haul and the Red had the lowest (31 ± 11.5%).

Grand means ± standard deviation (SD) for the Nile strains and the red variety for initial weight, individual harvest weight, weight gain, FCR, condition (K), survival, and yields are presented in Table 7. Initial stocking weights (g/fish) were larger for the Nile strains (102.4 ± 5.7) compared to the Red strain (94.0 ± 5.4) (P =0.015). Condition was greater for the Red strain (2.1 ± 0.23) compared to the Nile strain (1.8 ± 0.19). Survival was greater for the Nile strains (97.3 ± 8.6) compared to the Red strain (78.8 ± 13.9) (P = 0.004). Final standing crop (kg/ha) was greater for the Nile strain (13,684 ± 1,312) compared to the Red strain (9,507 ± 396) (P = 0.000). Percent of final standing crop as male (%) was greater for the Red strain (99.0 ± 1.0) compared to the Nile strain (83.9 ± 10.6) (P = 0.013). Final standing crop as reproduction (%) was greater for the Nile strain (15.5 ± 10.4) compared to the Red strain (0.0 ± 0.0) (P = 0.01).

Grand means ± standard deviation (SD) for the domestication status of fish and their initial weights, individual harvest weight, weight gain, survival, FCR and final standing crops are presented in Table 9. Initial stocking weights (g/fish) were found to be larger for the domesticated lines (105.3 ± 5.9) compared to the less domesticated lines (99.6 ± 3.9) (P = 0.041). There were no significant differences in all other parameters measured.

Discussion

Nile tilapia strains

Nile tilapia have a very wide natural distribution, including the Nile drainage from its headwaters in Ethiopia and Kenya to the Nile Delta in Egypt, the Niger drainage, and many lakes, and streams that were historically connected to these drainages (Trewavas, 1983). However, cultured stocks of Nile tilapia are based on a limited number of collections from the wild, often with a limited number of fish in the founding population (Khater and Smitherman, 1988; Pullin and Capili, 1988). The stocks used in this study reflect the range in natural distribution as well as small founding populations when introduced elsewhere for culture. The Ivory Coast strain had its origins from the tributaries of the Niger and Lake Volta (Trewavas, 1983), the Egypt strain from the Ismailia canal of the Nile delta (Khater and Smitherman, 1988), the Sagana strain originated from Lake Turkana (Osure and Phelps, 2006), and the Lake Victoria strain although from Lake Victoria is not native to the lake and was introduced in the 1950's from Lake Edward (Kaufman, 1992).

Although the Nile strains differed in their history, their final standing crops were similar and all were above that of the red strain. Final standing crops ranged from 9,508 ± 396 kg/ha for the red strain to 14,438 ± 779 kg/ha for the Sagana strain of Nile tilapia after the 120 day culture period. Diana et al. (2004) stocked males of an unspecified strain of Nile tilapia at $3/m^2$ into earthen ponds and obtained yields of 11,850 kg/ha in a 155 d study and 13,027 kg/ha in a 194 d study. Tayamen (2004) presented on-farm pond production results for the genetically improved Nile strain, Get-Excel, and reported a yield of 11,387 kg/ha in 212 d in one case and 13,882 kg/ha in a 216 d period in another. In Jamaica, average on-farm yields of Nile tilapia stocked at $2.5/m^2$ were 8,100 kg/ha/crop with an average of two crops/yr (Hanley, 2000).

Differences in growth among Nile tilapia strains have been reported by several authors under a variety of culture conditions, initial fish sizes and lengths of culture periods. Jayaprakas et al. (1988) found that the Auburn-Egypt strain fingerlings grew faster than the Ivory Coast when held in hapa and fed a commercial feed; after 60 d the average individual weights for the two strains were 24.5 ± 1.7 and 20.8 ± 1.6 g, respectively. Khater and Smitherman (1988) compared the communal growth of the Egypt, Ghana and Ivory Coast strains of Nile tilapia in earthen ponds and found that the Egypt strain grew the fastest (1.63 g/d) and the Ghana strain the slowest (1.35 g/d) in a 102 d period. Basiao and Doyle (1989) studied the growth of 10 full-sib families from each of three *O. niloticus* strains, CLSU (Central Luzon State University), Israel and NIFI (National Inland Fisheries Institute), in a crowded environment and found significant differences in growth rates. The CLSU strain had 7% higher growth rate than Israel and NIFI strains ($P = 0.05$). Marengoni et al. (1998) working in Japan using 800 L tanks compared the growth of mixed sex fingerlings from three strains of Nile tilapia of Egyptian origin, the Stirling strain introduced in 1992, a Korean strain introduced in 1992 and a local strain first introduced from the United Arab Emirates in 1975. In a three month period, the Stirling strain gained 0.72 ± 0.04 g/d while the other two strains gained less. Eknath et al. (1993) evaluated the growth performance of eight different strains (Egypt, Ghana, Kenya, Senegal, Israel, Singapore, Taiwan and Thailand) of Nile tilapia in communal extensive and intensive farm environments for 90 days. The results over two consecutive generations indicated highly significant differences in growth performances. Moreover, with the exception of the Ghana strain, the newly introduced Afican wild strains (Egypt, Ghana, Kenya and Senegal) performed as well as or better than the most widely farmed Asian strains (Israel, Singapore, Taiwan and Thailand).

O. niloticus from different geographical regions have similar coloration (Mires, 1988). Their dorsal region is black, the middle section is olive and the ventral, silvery white. Red coloration mainly around the head can be seen under the black pigmentation. These red areas become brighter during breeding season, especially in males. Wild type *O. niloticus* typically have vertical stripes on tail and dorsal fin. The vertical stripes along the caudal and dorsal fins were distinctive in the less domesticated strains (Lake Victoria and Sagana) while less pronounced in the domesticated (Egypt and Ivory Coast) strains. The Sagana strain exhibited distinctive vertical black bars along lateral sides and brilliant bluegreen hues throughout.

The Sagana strain demonstrated the highest weight gain (369 ± 28g), male harvest weight (473 ± 30g) and final standing crop (14,438 ± 779 kg/ha) among all strains. Liti et al. (2005) compared growth, survival, and reproduction of three strains (Lake Victoria, Lake Turkana and Sagana) of Nile tilapia cultured in earthen ponds for 128 days. They concluded that the Lake Victoria strain was superior in all aspects while the Turkana and Sagana strains had lower but similar performance. The percent of final standing crop as male was higher (93.7 ± 7.8%) for the Sagana strain versus an average of 80.7 ± 4.8% for the other Nile strains. Male tilapia grow faster than females (Baras and Melard, 1997; Ponzoni et al., 2005; Toguyeni et al., 2002). Furthermore, the Sagana strain had a relatively low number of females present at harvest (Table 3). Lovshin et al. (1990) reported significant differences in mean male tilapia growth when stocked with all male, 2.5% female and 5.0% females relative to competition for growth from offspring that were detectable at four months of culture. Therefore, the observed production advantage of the Sagana strain may be attributed to a larger percentage of males and relatively low number of females present at harvest.

Domestication/Inbreeding

The number of animals in a founding population and the degree of inbreeding in subsequent generations will impact the genetic diversity of the population (Wright, 1931; Nei et al. 1975; Chakraborty and Nei, 1977). All five strains evaluated were based on relatively small founding populations but they differed in the years of domestication. The Ivory Coast strain introduced to Auburn University in 1974 has been in culture the longest of any of the strains tested and the Lake Victoria the least, having been collected from Lake Victoria in 2002. Osure (2003) compared the genetic characteristics of the Nile strains used in this study and found that the Ivory Coast strain had the lowest heterozogosity and the fewest private alleles while the Lake Victoria strain had the greatest heterozogosity and number of private alleles and attributed this to differences in inbreeding.

There was no apparent inbreeding depression as a reflection of how long a given strain has been in culture. The Sagana strain introduced from the wild in the early 1980's had the highest growth rate of any of the Nile strains tested while the Lake Victoria strain, the most recently domesticated, had a growth rate similar to the Ivory Coast strain, the strain which had been domesticated the longest (Table 8). Eknath et al (1993) reported on the ICLARM's breeding program where "wild" strains of Nile tilapia were collected Egypt, Ghana, Kenya, and Sénégal were compared to Asian farmed "domesticated" strains. They found that three of the four African wild strains (Egypt, Kenya, and Sénégal) grew as well as or faster than the Asian farmed "domesticated" strains (Israel, Singapore, Taiwan and Thailand) across several test environments

Red vs. Nile tilapia strains

Tilapia with a “Red” color pattern have appeared in several species of tilapia and their hybrids including Nile tilapia (Galman and Avtalion, 1983). The red color pattern has been favored in some markets over the wild color pattern (Lovshin, 2000). In the Philippines, red tilapia were reported to sell for twice the price of Nile tilapia (Romana-Eguia and Eguia, 1999). Popma and Rodriguez (2000) reported that in southern Colombia the value of gutted Nile tilapia in 1997 was 25% of the value of red tilapia. Such higher prices may be necessary to compensate for some of the production characteristics of red tilapia.

Overall, the mean average weight of males at harvest for the Nile strains was similar to the red strain, 404.7 ± 52.17g vs 410.9 ± 54.4 g; however, the red strain had a lower final standing crop of males of 9,450 ± 373 kg/ha compared to that of the yield of males for the Nile strains of 11,630 ± 1,803 kg/ha due to the lower survival of the red tilapia. In this study, the survival of red tilapia averaged 78.8 ± 13.9% vs. 97.3 ± 8.6% for the Nile strains. Green et al. (1994) compared the production of red and Nile tilapia in communally stocked ponds and obtained a red tilapia survival of 37 % and 83 % survival for Nile tilapia. They concluded that bird predation was the major cause of low red tilapia survival. In more controlled settings, red tilapia survival has been less of an issue. Moreira et al. (2005) compared the Chitralada strain of Nile tilapia to the Red-Stirling strain in cages and obtained survivals of > 99% for both. Romana-Equia et al. (2010) evaluated three strains of red tilapia and one natural colored Nile strain in indoor aquaria and found that the red strains had equal or better survival than the Nile strain. In our outdoor setting, the tanks were not covered and birds had access to the fish production units.

The individual growth of the red tilapia was equal or greater than three of the four Nile strains. Red tilapia growth has been found to be similar in some cases and slower in others

relative to Nile tilapia depending on setting and strains being used. Green et al. (1994) compared the performance of 10 g sex-reversed fingerlings from a mating of Florida red tilapia x *O. niloticus* with wild-type *O. niloticus* stocked at 2/m^2 in fertilized earthen ponds fertilized with chicken manure and chemical fertilizers and were fed a pelleted ration. Average weights of Nile and red tilapias were 252 and 253 g, respectively. Ng and Hanim (2007) compared production characteristics of Nile tilapia (GIFT strain, F9 generation) and a red tilapia hybrid. The fish were cultured for 70 days in aquaria and fed a 35% protein feed. They found that the GIFT fish were larger with a mean weight of 65.6 ± 1.99 and had a more efficient FCR of 1.35 ± 0.01 while red tilapia mean weight averaged 43.3 ± 1.48 g with a FCR of 1.80 ± 0.03.

Physiochemical (temperature, oxygen, ammonia, etc.), food and nutrient availability, light regime, water current speed, predator density, intraspecific social interactions and genetics have an effect on growth and condition (Wootten, 1990). Condition factors (K) observed herein were similar to results (range = 1.89 ± 0.03 to 2.06 ± 0.03) obtained by El-Saidy and Graber (2005) culturing juvenile (61.9 ± 6.4 g) *O. niloticus* in concrete tanks at a density of 25 fish/m^3. A difference ($P < 0.0001$) was observed in condition (K) between Nile strains (1.8 ± 0.19) and the Red strain (2.1 ± 0.23). A negative correlation ($R^2 = 0.44$; $P = 0.002$) was detected between condition and final standing crop. As final standing crop decreased condition increased (Figure 5).

Seinability

Ease of harvest is another production characteristic of importance with tilapia. In this study, the ease of capture was evaluated for fish held in tanks with a concrete bottom and vertical sides. An average of 41 ± 8.8% of the adults were captured in the first seining. After three seinings, an average of 96.8 ± 0.05% was captured. There were no significant differences among

the strains relative to seinability. Sifa et al. (1999) compared the seinability of four strains of Nile tilapia in earthen ponds in 1995 and 1996. The accumulated seinability of the GIFT, Egypt 88, Sudan 78 and Egypt 92 strains was compared based on three trawls. Seinability of the GIFT strain was higher ($P<0.01$) than that of other strains. In 1995, the seinability of the GIFT line (67% of the population captured) was higher than that of Egypt 88 (38%), Sudan 78 (23%) and Egypt 92 (22%). In 1996, the seinability of the GIFT line (81.5%) was higher than that of the Egypt 88 strain (62%). Difference in the culture systems may explain the differences in results. Sifa et al. (1999) carried out experiments in relatively deeper earthen ponds versus the shallow concrete tanks of this work. The solid bottom of the concrete tank provides a smooth surface for seining compared to an uneven earthen pond bottom typical of tilapia production ponds. In this study, the seine extended out of the water for the majority of its length reducing the chance for fish escapement over the top.

Factors affecting the results

A 24 g difference in initial weights among all replicates contributed to a correlation ($R^2 = 0.24$, $P = 0.032$) of lower final standing crop of males to higher initial weight of males stocked (Figure 1). A positive correlation ($R^2 = 0.46$; $P = 0.001$) among all strains was noticed between mean final standing crop (kg/ha) and mean percent (%) survival (Figure 2). There were no correlations found among percent survival and mean unionized ammonia, frequency of unionized ammonia or frequency of low dissolved oxygen. However, a positive correlation was observed between percent survival and initial weight ($R^2 = 0.22$, $P = 0.04$) (Figure 3).

Males used in this study were manually selected however there was a mean sexing error of 1.92 ± 1.14% resulting in 68.4 % of the tanks containing fingerlings at harvest. No one strain was more difficult to sex. Females were removed when found during the monthly samples and

largemouth bass were added after month 1. Red tilapia fingerlings were observed during the Month 1 sample but none were present at harvest. The average size of the Nile tilapia fingerlings (13.1 g) and the uniformity of size suggest that largemouth bass stocked at 0.01/ha were effective in controlling any later tilapia reproduction. Average largemouth bass production was 20 kg/ha with a 39.6% survival. McGinty (1985) found that largemouth bass stocked at 1.4 fish/100 m^2 was effective in limiting tilapia reproduction to being 8% of the tilapia biomass when a 90% male tilapia population was stocked at 9,500/ha. Other authors have also used predacious fish to control tilapia reproduction when culturing near-all male tilapia (Swingle, 1966; Chervinski, 1974; Dunseth and Bayne, 1978; Ramos-Henao and Corredor, 1980; Hopkins et al., 1982; McGinty, 1983, 1984).

A small number of female tilapia can result in a significant quantity of reproduction, if unchecked, and depress growth of the adults. The greatest quantity of reproduction occurred in the Ivory Coast strain tanks and contributed 21.7 ± 9.22% of the final standing crop (13,701 ± 1,493 kg/ha) resulting from an equivalent of 660 females/ha (2.8 ±1.25% of population). Overall, as the percent of final standing crop as reproduction increased, mean male weight decreased (R^2 = 0.44; P = 0.001) for all strains including the Red which had no harvestable reproduction; R^2 = 0.68; P < 0.0001 for Nile strains only) (Figure 4). Anderson and Smitherman (1978) present data on the culture of male Nile tilapia in ponds when given a commercial feed for 103 d where there was an error in sexing. At harvest, the final standing crop was 4,210 kg/ha with an average of 2.6% of the adults being females where no predators were added to control reproduction. Reproduction (kg) was 38.5% of the final standing crop. Lovshin et al. (1990) stocked 11g male tilapia hybrids into earthen ponds at 10,000, 9,750 and 9,500/ha along with females at 0/ha, 250/ha and 500/ha, respectively with no predators. Total fish yields (kg stocked tilapia +

reproduction) after nine months of culture were not significantly different among treatments. However, the treatment stocked with 5% females gave a total yield of 5,451 kg/ha but 59.9% of the total yield was reproduction. Average weight of males in this treatment was 285 ± 35 g compared to 481 ± 36 g in the 100% male treatment where no reproduction was found. Mair and Van Dam (1996) compared the effects of the percent females in a population stocking 21 g Nile tilapia into fertilized ponds in a 126 d study. They found that where females were stocked at 2% or 5% of the population, the reproduction represented 7.83 ±1.83 and 7.86 ± 2.81 % of the harvest and males had gained 28.1 ± 15.73 and 30.4 ± 8.50 g, respectively, but where no females were present the average gain was 33.3 ± 6.11g.

Conclusion

Among the Nile strains evaluated under the intensive outdoor culture conditions of this research station, there were no distinct production advantages among the Nile strains or domestication status. However, there was a positive production advantage of the Nile strains over the Red variety relative to survival.

Table 1
Mean (±SD) for initial weight (g/fish), male harvest weight (g/fish), male weight gain(g), growth (g/day), condition (K), final standing crop (FSC) (kg/ha), FSC as male (kg/ha), FSC as female (kg/ha), FSC as reproduction (kg/ha)(including Red strain data), FSC as reproduction (kg/ha)(excluding Red strain data), percent FSC as male (%), percent FSC as female (%), percent FSC as reproduction (%) (including Red strain data) and percent FSC as reproduction (%) (excluding Red strain data), from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Parameter	**Egypt (n=3)**	**Ivory Coast (n=4)**	**Lake Victoria (n=4)**	**Sagana (n=4)**	**Red (n=4)**	**P-Value**
initial weight	111 ± 2.4[a]	100 ± 1.7[b]	98 ± 2.2[b]	102 ± 4.7[b]	94 ± 5.4[b]	0.000
male harvest wt.	400 ± 52[ab]	380 ± 20[a]	365 ± 37[a]	473 ± 30[b]	413 ± 54[ab]	0.020
male weight gain	296 ± 44[ab]	276 ± 18[b]	268 ± 38[b]	369 ± 28[a]	317 ± 58[ab]	0.018
growth	2.5 ± 0.7	2.3 ± 0.5	2.3 ± 1.1	3.1 ± 0.7	2.7 ± 1.3	0.681
condition	1.8 ± 0.12[a]	1.8 ± 0.16[a]	1.8 ± 0.14[a]	1.8 ± 0.28[a]	2.1 ± 0.23[b]	0.000
FSC	13,405 ± 146[a]	13,912 ± 2108[a]	12,914 ± 1129[a]	14,438 ± 779[a]	9,508 ± 396[b]	0.000
FSC as male	11,667 ± 1,648	10,761 ± 2,338	10,204 ± 1,271	12,847 ± 1,817	9,450 ± 373	0.083
FSC as female	38.4 ± 34.0	84.3 ± 34.5	142.3 ± 53.6	62.9 ± 49.4	96.4 ± 95.1	0.237
FSC as reproduction	2,430 ± 1,896[ab]	3,062 ± 1,447[a]	2,568 ± 939[ab]	879 ± 1,154[bc]	0 ± 0[c]	0.017
FSC as reproduction Red excluded	2,430 ± 1,896	3,062 ± 1,447	2,568 ± 939	879 ± 1,154	NA	0.2
% FSC as male	86.1 ± 11.4[ab]	77.0 ± 9.5[b]	79.0 ± 7.5[b]	93.7 ± 7.8[ab]	99.0 ± 1.0[a]	0.006
% FSC as female	0.29 ± 0.26	0.61 ± 0.25	0.87 ± 0.27	0.43 ± 0.34	1.0 ± 0.99	0.372
% FSC as reproduction	12.9 ± 11.1[abc]	22.4 ± 9.4[b]	20.1 ± 7.3[abc]	5 .9 ± 7.5[abc]	0 ± 0.0[c]	0.008
% FSC as reproduction Red excluded	12.9 ± 11.1	22.4 ± 9.4	20.1 ± 7.3	5 .9 ± 7.5	NA	0.084

Table 2
Mean (±SD) for seinability (% capture/one seine haul), survival (%), and feed conversion ratio (FCR), Male average harvest weight from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Parameter	**Egypt (n=3)**	**Ivory Coast (n=4)**	**LakeVictoria (n=4)**	**Sagana (n=4)**	**Red (n=4)**	**P-Value**
Seinability	42 ± 8.7	52 ± 8.8	34 ± 14.1	46 ± 11.5	31 ± 11.5	0.098
Survival	98.3 ± 1.7	97.1 ± 16.5	96.7 ± 7.8	97.5 ± 2.9	78.8 ± 13.9	0.101
FCR	1.5 ± 0.41	1.3 ± 0.18	1.4 ± 0.12	1.3 ± 0.09	1.9 ± 0.08	0.145

Table 3
Mean (±SD) for numbers and weights (g) of females harvested per 20 m^2 by treatment at days 60, 90 and total harvest(kg/ha) from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Parameter	Egypt (n=3)	Ivory Coast (n=4)	Lake Victoria (n=4)	Sagana (n=4)	Red (n=4)	P-Value
Female # 60 day	0.25 ± 0.5	0.5 ± 0.58	0.5 ± 0.58	0.5 ± 0.58	0.5 ± 0.58	0.956
Female wt 60 day	102.7 ± 0.0	137.0 ± 47.0	125.7 ± 42.5	154.4 ± 83.8	160.2 ± 25.5	0.889
Female # 90 day	0	0	0.25 ± 0.5	0	0	0.438
Female wt 90 day	0	0	138.0 ± 0.0	0	0	.
Total Harvest Female (#)	0.5 ± 0.58[b]	1.25 ± 0.50[ab]	2.25 ± 0.96[a]	1.0 ± 0.81[ab]	0.75 ± 0.50[ab]	0.0256
Total Harvest Female (g)	77.9 ± 69.0	170.7 ± 70.0	319.1 ± 124.8	127.2 ± 100.0	195.1 ± 192.6	0.151

Table 4
Mean (±SD) final individual length (mm) and weight (g) of reproduction at harvest from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Parameter	**Egypt (n=3)**	**Ivory Coast (n=4)**	**Lake Victoria (n=4)**	**Sagana (n=4)**	**Red (n=4)**	**P-Value**
Final Mean Reproduction Length (mm)	12.5 ± 3.1	12.4 ± 1.4	12.0 ± 1.5	12.9 ± 3.6	NA	0.972
Final Mean Reproduction Weight (g)	43.4 ± 37.5	37.5 ± 13.5	33.2 ± 14.2	45.3 ± 35.8	NA	0.921

Table 5
Mean (±SD) density (#/m^2), total weight (g), individual weight (g) and final standing crop (kg/ha) of largemouth bass at harvest from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial 36% protein floating feed for 120 days.

Parameter	**Egypt (n=3)**	**Ivory Coast (n=4)**	**Lake Victoria (n=4)**	**Sagana (n=4)**	**Red (n=4)**	**P-Value**
density	0.09 ± 0.09	0.09 ± 0.03	0.14 ± 0.08	0.03 ± 0.03	0.15 ± 0.07	0.084
total weight	26.8 ± 17.0	22.9 ± 17.7	37.9 ± 28.1	13.9 ± 3.8	38.0 ± 18.8	0.571
individual weight	11.3 ± 2.9	12.2 ± 8.0	13.3 ± 6.2	13.9 ± 3.8	14.7 ± 7.9	0.962
final standing crop	9.9 ± 9.5	12 ± 8.2	18.7 ± 13.9	3.4 ± 4.1	25.8 ± 11.7	0.057

Table 6
Mean (±SD) for temperature (^{o} C), dissolved oxygen (mg/L), frequency (# days/120 days) of dissolved oxygen (%) ‹ 2.0 mg/L, pH, frequency of pH≥ 10, total alkalinity (mg/L), hardness (mg/L), chloride (mg/L), nitrite (mg/L), unionized ammonia (mg/L), frequency of unionized ammonia ≥ 1.0, and flush frequency (#/month) from a static outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial 36% protein floating feed for 120 days.

Parameter	**Egypt (n=3)**	**Ivory Coast (n=4)**	**Lake Victoria (n=4)**	**Sagana (n=4)**	**Red (n=4)**	**P-Value**
Temperature	30.3 ± 0.2	30.3 ± 0.2	30.4 ± 0.1	30.4 ± 0.1	30.3 ± 0.1	0.5767
Dissolved O_2	4.2 ± 0.4	4.2 ± 0.4	4.1 ± 0.3	4.1 ± 0.4	4.1 ± 0.1	0.9922
Frequency < 2 mg/L O_2	7.3 ± 4.2	9.3 ± 5.6	6.1 ± 4.4	9.3 ± 5.1	8.0 ± 0.9	0.8105
pH	8.1 ± 0.2	8.0 ± 0.2	8.0 ± 0.1	8.2 ± 0.1	8.1 ± 0.3	0.5732
Frequency ≥ 10 pH	6.8 ± 4.6	4.6 ± 5.3	4.6 ± 5.3	6.8 ± 8.7	6.8 ± 4.6	0.9452
Alkalinity	73.0 ± 4.8	86.3 ± 4.0	82.3 ± 5.9	80.0 ± 18.8	75.0 ± 5.6	0.9619
Hardness	72.2 ± 4.3	73.2 ± 3.8	77.0 ± 7.4	76.3 ± 16.1	66.5 ± 3.4	0.4565
Chloride	17.6 ± 1.6	18.5 ± 1.9	20.1 ± 1.5	20.2 ± 2.9	21.5± 3.3	0.2052
Nitrite	0.7 ± 0.3	0.5 ± 0.2	0.6 ± 0.3	0.9 ± 0.3	0.6± 0.2	0.4764
NH_3	0.2 ± 0.1	0.4 ± 0.4	0.3 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.3111
$NH_3 \geq 1.0$ Frequency	2.8 ± 5.6	2.8 ± 5.6	5.6 ± 6.4	2.8 ± 5.6	0.0 ± 0.0	0.6838
Flush Frequency	1.1 ± 0.3	0.8 ± 0.3	0.9 ± 0.2	1.1 ± 0.4	0.9 ± 0.2	0.2275

Table 7
Mean (±SD) for initial weight (g/fish), male harvest weight (g/fish), male weight gain(g), FCR, condition (K), survival (%), final standing crop (FSC) (kg/ha), FSC as reproduction (kg/ha), percent FSC as male (%), percent FSC as female (%), and percent FSC as reproduction (%) of all Nile (*Oreochromis niloticus*) tilapia strains compared the red (Santa Fe) tilapia variety from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Parameter Mean	**Nile strains (n=15)**	**Red strain (n=4)**	**P-Value**
Initial weight	102.4 ± 5.7	94.0 ± 5.4	0.015
Male harvest weight	404.7 ± 53.8	412.5 ± 53.8	0.799
Male weight gain	302.3 ± 50.9	317.3 ± 57.7	0.614
FCR	1.9 ± 0.47	1.7 ± 0.39	0.463
Condition	1.8 ± 0.19	2.1 ± 0.23	0.000
Survival	97.3 ± 8.6	78.8 ± 13.9	0.004
FSC	13,684 ± 1,312	9,507 ± 396	0.000
% FSC as male	83.9 ± 10.6	99.0 ± 1.0	0.013
% FSC as female	1.3 ± 1.4	0.6 ± 1.2	0.378
% FSC as reproduction	15.5 ± 10.4	0.0 ± 0.0	0.010

Table 8
Regression analysis modeled for the independent variables of initial weight (g/fish), weight gain (g/fish), survival (%) and condition (K) to the dependent variables of harvest weight (g/fish), weight gain (g/fish) and survival (%), condition and final standing crop (FSC) (kg/m^3) of all Nile (*Oreochromis niloticus*) tilapia strains compared the red (Santa Fe) tilapia variety from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Dependent variable	**Independent variable**			
	stocking weight	weight gain	survival	condition
harvest weight	P = 0.95	R^2 = 0.99, P < 0.000	P = 0.44	P = 0.73
weight gain	P = 0.60	.	P = 0.31	P = 0.61
survival	R^2 = 0.22, P = 0.04	P = 0.31	.	P = 0.09
condition	P = 0.15	P = 0.61	P = 0.09	.
FSC	R^2 = 0.24, P = 0.03	P = 0.72	R^2 = 0.56, P < 0.000	R^2 = 0.44, P = 0.002

Table 9
Mean (±SD) for initial weight (g/fish), male harvest weight (g/fish), male weight gain(g), FCR, condition (K), survival (%), final standing crop (FSC) (kg/ha), percent FSC as male (%), percent FSC as female (%), and percent FSC as reproduction (%) from two domesticated strains (Egypt and Ivory Coast) Nile tilapia (*Oreochromis niloticus*) and two strains of less domesticated strains (Lake Victoria and Sagana)from a static intensive outdoor production system where tilapia were stocked at 3 fish/m^2 and fed a commercial diet of 36% protein floating feed for 120 days.

Parameter Mean	**Domesticated (n=7)**	**Less Domesticated (n = 8)**	**P-Value**
Initial weight	105.3 ± 5.9	99.6 ± 3.9	0.041
Male harvest weight	388.6 ± 34.8	418.8 ± 65.3	0.295
Male weight gain	286.0 ± 33.2	318.6 ± 62.0	0.211
FCR	1.9 ± 0.47	1.7 ± 0.39	0.390
Condition	1.8 ± 0.14	1.8 ± 0.22	0.133
Survival	97.6 ± 11.7	97.1 ± 5.5	0.911
FSC	13,695 ± 1,518	13,676 ± 1,212	0.979
% FSC as male	81.2 ± 10.8	86.3 ± 10.6	0.368
% FSC as female	0.47 ± 0.29	0.65 ± 0.37	0.326
% FSC as reproduction	18.3 ± 10.6	13.0 ± 10.2	0.341

Figure 1
Relationship between mean final standing crop (FSC) (kg/ha) and mean initial weight (g) of tilapia stocked at a density of 3 fish/m^2 in an outdoor static production system and fed a commercial 36% protein floating feed for 120 days.
(R^2 = 0.24) (P = 0.03)

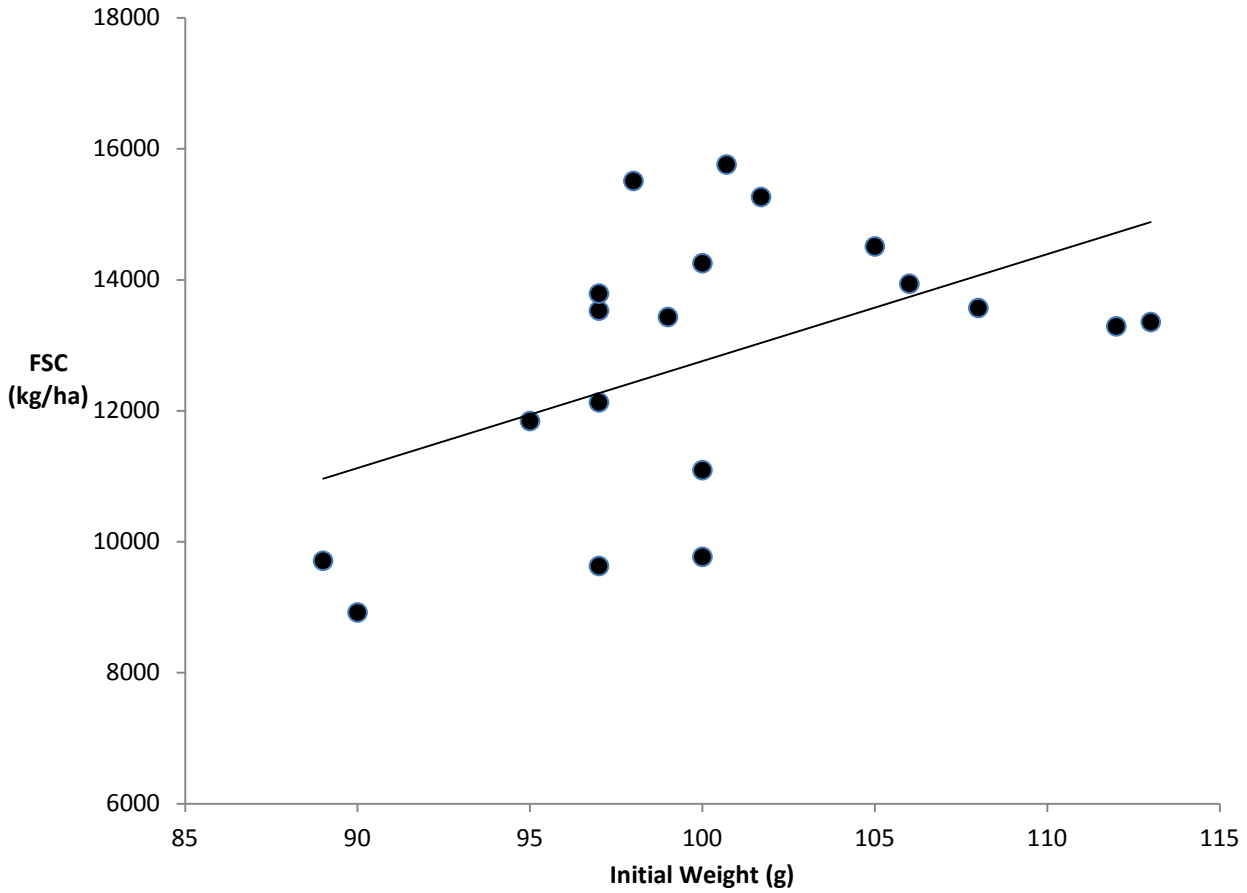


Figure 2
Relationship between mean final standing crop (FSC) (kg/ha) and mean percent (%) survival of tilapia stocked at a density of 3 fish/m^2 in an outdoor static production system and fed a commercial 36%protein floating feed for 120 days.
(R^2 = 0.46) (P = 0.001).

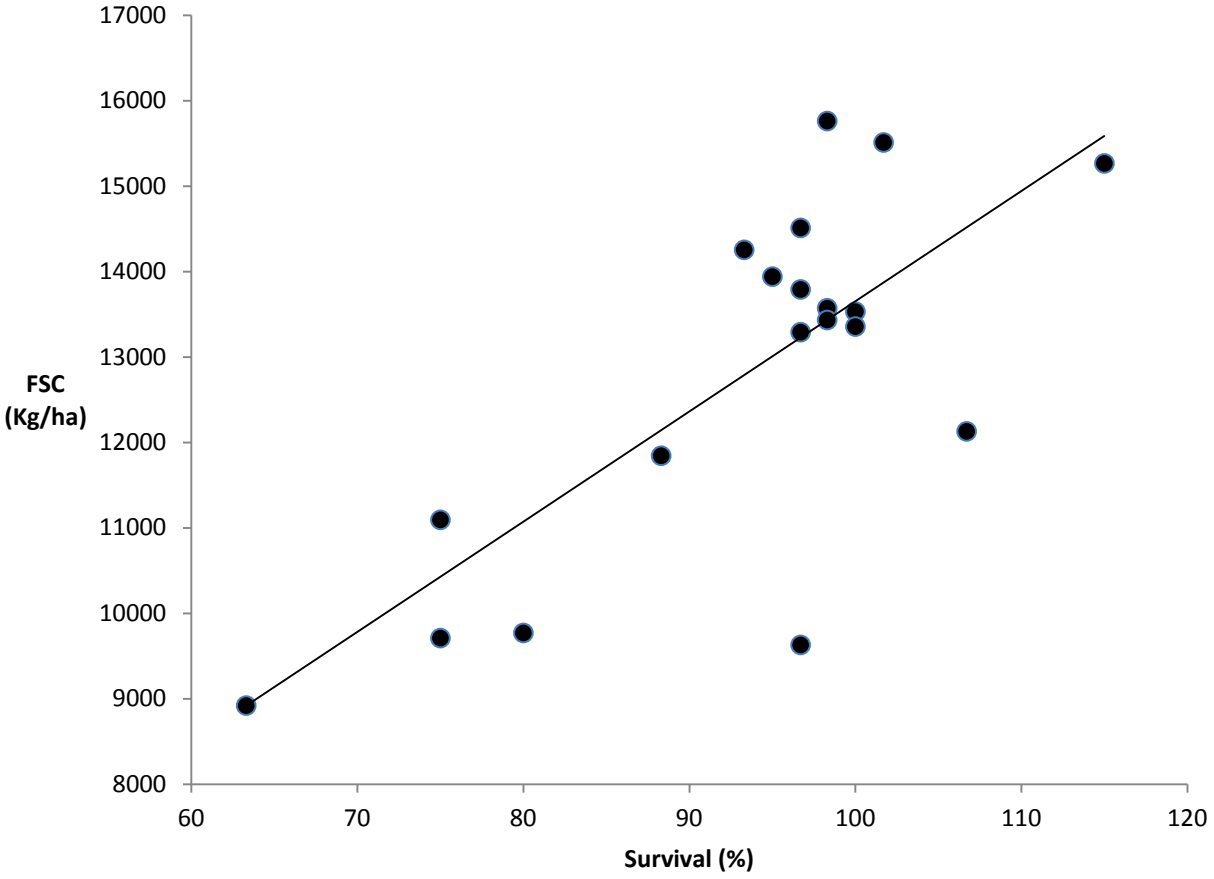


Figure 3
Relationship between survival (%) and initial weight (g/fish) of tilapia stocked at a density of 3 fish/m^2 in an outdoor static production system and fed a commercial 36% protein floating feed for 120 days.
(R^2 = 0.22) (P = 0.03).

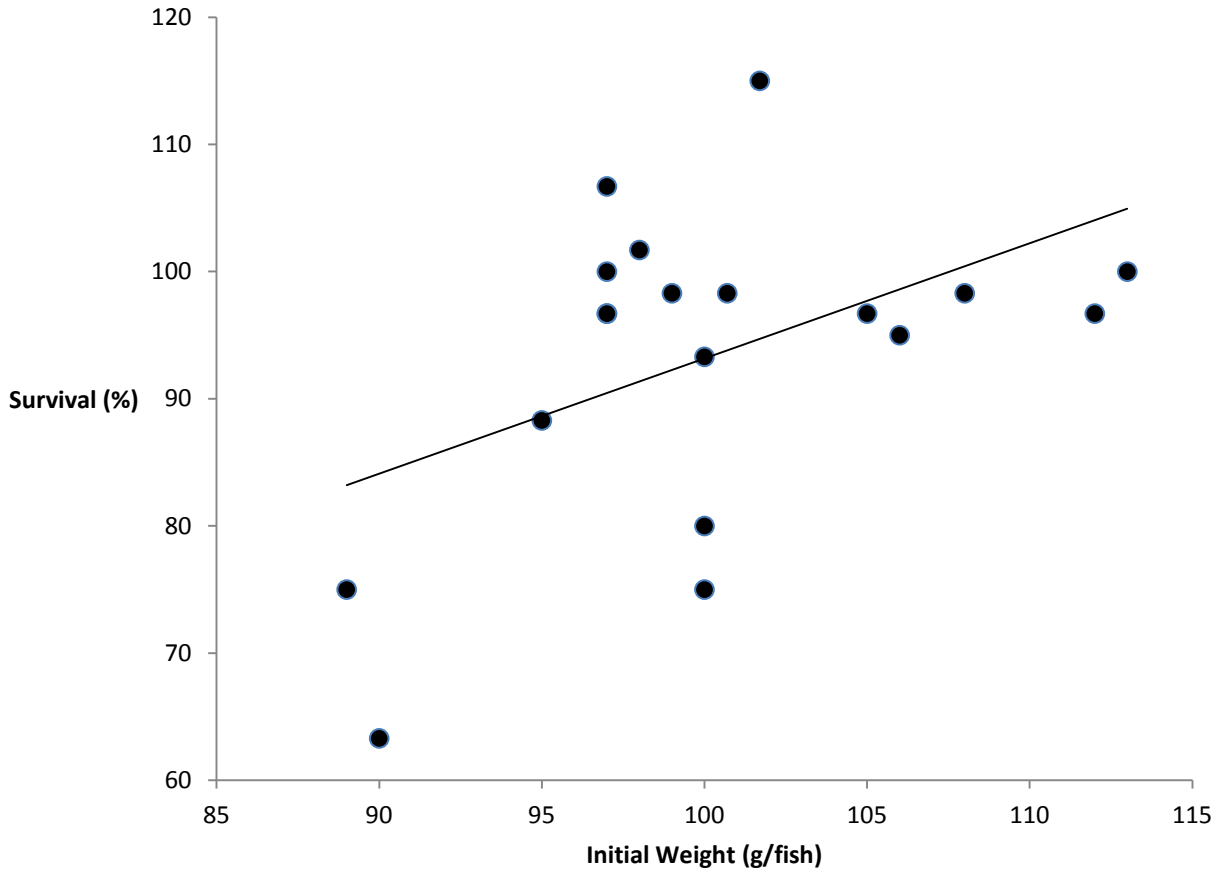


Figure 4
Relationship among all Nile strains between mean male harvest weight (g) and mean percent (%) final standing crop (FSC) as reproduction of tilapia stocked at a density of 3 fish/m^2 in an outdoor static production system and fed a commercial 36% protein floating feed for 120 days. ($R^2 = 0.68$) ($P < 0.0001$).

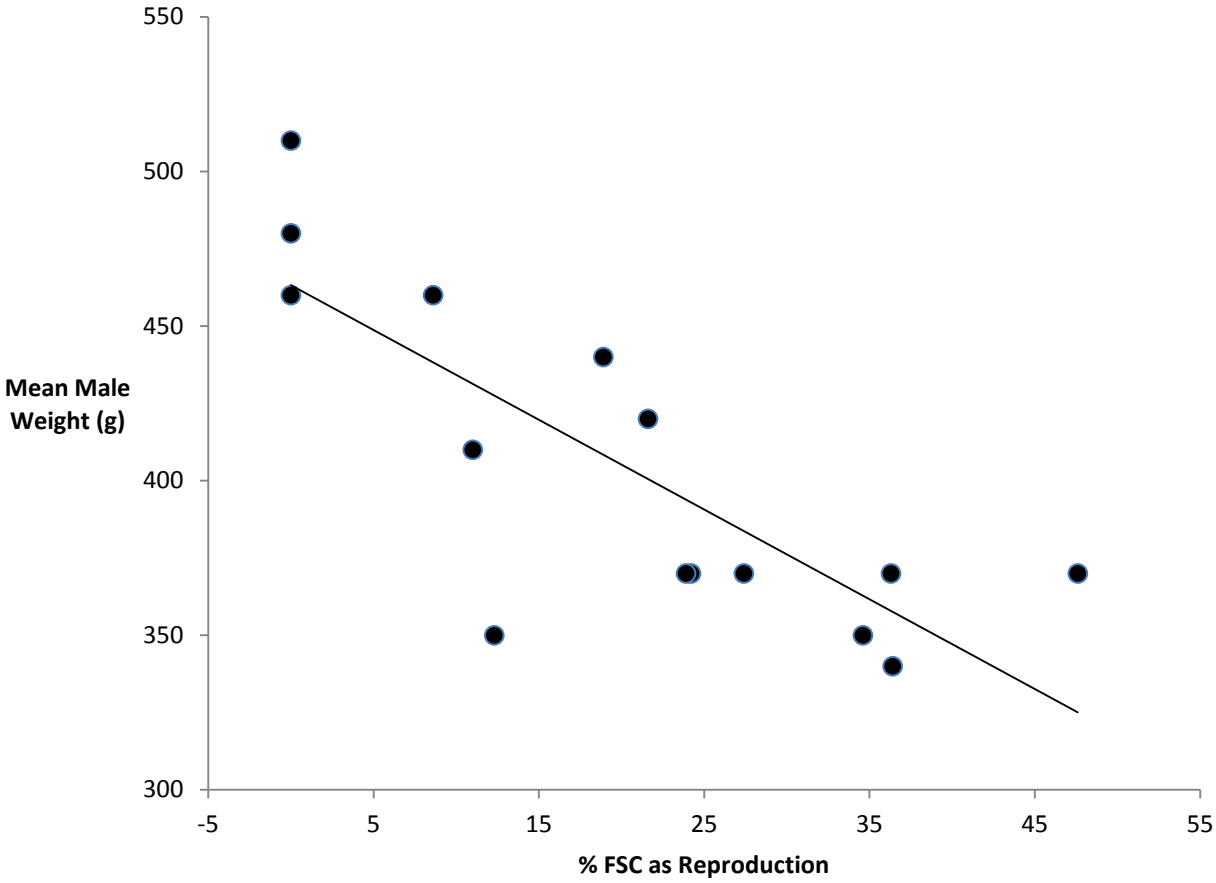
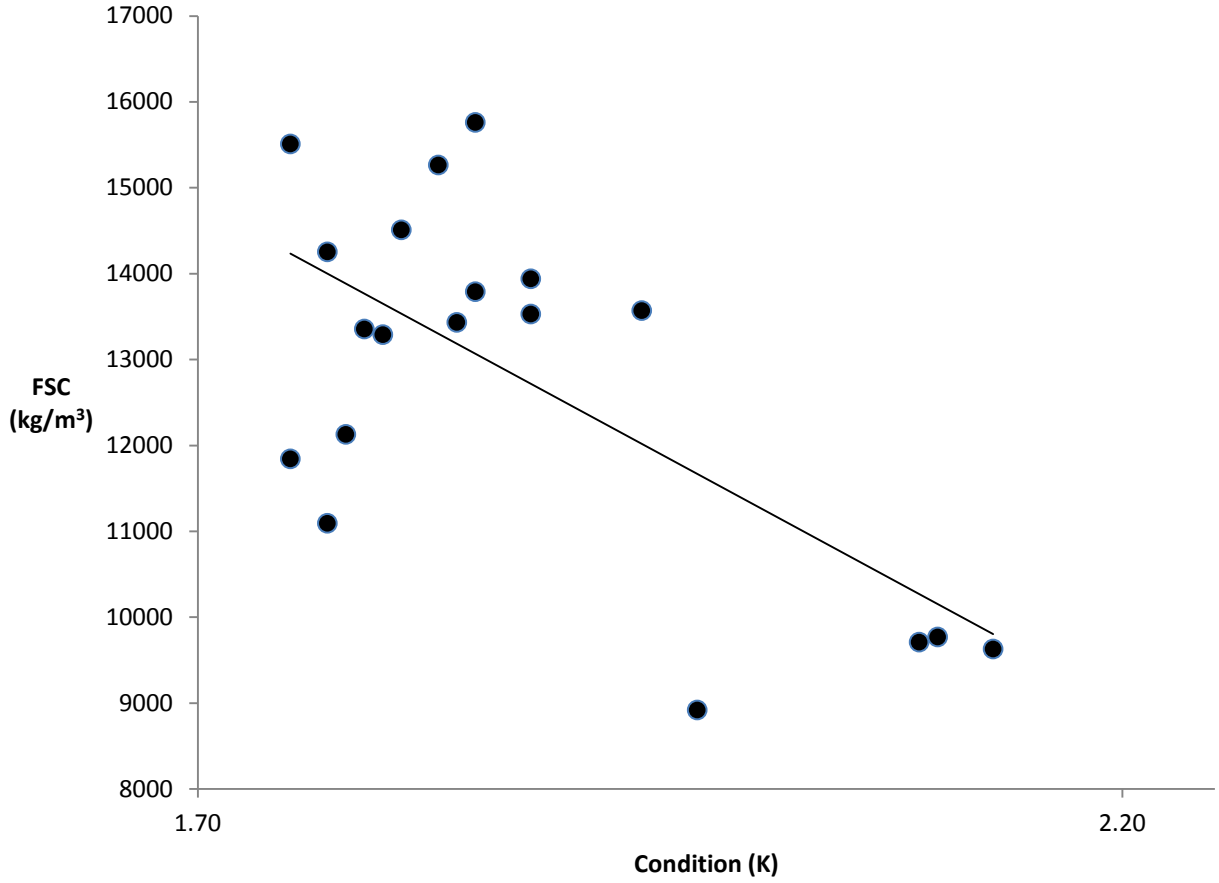


Figure 5
Relationship between mean fianl standing crop (FSC) (kg/ha) and mean condition (K) of tilapia stocked at a density of 3 fish/m^2 in an outdoor static production system and fed a commercial 36% protein floating feed for 120 days.
(R^2 = 0.44) (P = 0.02).



References

Anderson, C.E. and Smitherman, R.O., 1978. Production of normal male and androgen sex-reversed *Tilapia aurea* and *T. nilotica* fed a commercial catfish diet in ponds. in: Smitherman, R.O., Shelton, W.L. and Grover, S.H. (Eds.), *Culture of Exotic Fishes Symposium Proceedings*, Fish Culture Section, American Fisheries Society, Auburn, AL, pp. 34–42.

Baras, E. and Mélard, C., 1997. Individual growth patterns of juvenile Nile tilapia, *Oreochromis niloticus*. Emergence and dynamics of sexual growth dimorphism, in: Fitzsimmons, K. (Ed.), Tilapia Aquaculture, Proceedings from the Fourth International Symposium on Tilapia in Aquaculture 9–12 May 1997, Orlando, Florida, USA.NRAES, Volume 106. pp. 169–177.

Bardach, J.E., Ryther, J.H. and McLarney, W.O., 1972. Aquaculture, the farming and husbandry of fresh water and marine organisms. Wiley-interscience Inc. New York.

Basiao, Z.U. and Doyle, R.W., 1989. Use of internal reference population for growth rate comparison of tilapia strains: In a crowded environment, in: Hirano, R., Hanyu, I. (Eds.), The Second Asian Fisheries Forum. Proceedings of the Second Asian Fisheries Forum, Tokyo, Japan. Pp. 503–506

Bestari, N., 2004. An Impact Evaluation of Genetically Improved Farmed Tilapia and Their Dissemination in Developing Countries. Operations Evaluations Department. Asian National Bank. IES:Reeg 2004-20.

Bolivar, R., 1998. Estimation of response to within-family selection for growth in Nile tilapia. Doctoral dissertation, Dalhousie University, Halifax, Nova Scotia, Canada.

Brummett, Randall, 2004. On-farm and on-station comparison of wild and domesticated Cameroonian populations of *Oreochromis niloticus*. Aquaculture 242, 157-164.

Chakraborty, R. and Nei, M., 1977. Bottleneck effects on average heterozygosity and genetic distance with the stepwise mutation model. Evolution 31, 347-356.

Chervinski, J., 1974. Sea Bass, *Dicentrarchus labrax*, a "police fish" in freshwater ponds and its adaptability to various saline conditions. Bamidgeh 26, 110-113.

Dan, N.C. and Little, D.C, 2000. The culture performance of monosex and mixed sex new season and over-wintered fry in two strains on Nile tilapia (*Oreochromis niloticus*) in Northern Vietnam. Aquaculture 184, 221-231.

Diana, J.S., Yi, Y. and Lin, C.K., 2004. Stocking densities and fertilization regimes for Nile tilapia (*Oreochromis niloticus*) production in ponds with supplemental feeding. in: Bolivar, R., Mair, G. and Fitzsimmons, K. (Eds.), Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, Manila Phillipines, pp.487-499.

Doyle, Roger, 1983. An approach to the qualitative analysis of domestication selection in aquaculture. Aquaculture 33, 167-185.

Dunham, R.A. Brummett, R.E. Ella M.O. and Smitherman, R.O., 1990. Genotype–environment interactions for growth of blue, channel and hybrid catfish in ponds and cages at varying densities. Aquaculture 85, 143–151.

Dunseth, D.R. and Bayne, D.R., 1978. Recruitment control and production of *Tilapia aurea* with the predator *Cichlasoma managuense*. Aquaculture 14, 383-390.

Eknath, A.E., Tayamen, M.M., Palada-de Vera, M.S., Danting, J.C. and Reyes, R.A., 1993. Genetic improvement of farmed tilapias: the growth performance of eight strains of *Oreochromis niloticus* tested in different farm environments. Aquaculture 111, 171-188.

El-Saidy, D.M.S.D. and Gaber, M.M.A., 2005. Effect of dietary protein levels and feeding rates on growth performance, production traits and body composition of Nile tilapia, *Oreochromis niloticus* cultured in concrete tanks. Aquaculture Research 36, 163-171.

Fulton, T.W., 1911. The sovereignity of the sea. London: Edinburgh.

Green, B., Teichert-Coddington, D. and Hanson, T., 1994. "Development of Semi-Intensive Aquaculture Technologies in Honduras". R and D Series 39, International Center for Aquaculture and Aquatic Environments, Department of Fisheries and Allied Aquacultures, Auburn University, Alabama 36849, USA.

Hanley, F., 1991. Freshwater tilapia culture in Jamaica. World Aquaculture 22**,** 43–48.

Hanley, F., 2000. Tilapia aquaculture in Jamaica, in: Costa-Pierce, B.A. and J.E. Rakocy, (Eds.,). Tilapia Aquaculture in the Americas. Volume 2. Baton Rouge, Louisiana: The World Aquaculture Society, pp. 204–214

Hassan, A.S., Sayed, S.H. and Ibrahim, E.M., 2008. Effects of stocking rates and supplementary feed on the growth performance of Blue Tilapia (*Oreochromis aureus*) and grass carp (*Ctenopharyngodon idella*) reared in earthen ponds. Eighth International Symposium on Tilapia in Aquaculture. Central Laboratory for Aquaculture Research, Egypt.

Head, W.D., Zerbi, A. and Watanabe, W.O., 2004. Preliminary observations on the marketability of saltwater-cultured Florida red tilapia in Puerto Rico. Journal of the World Aquaculture Society 25, 432-441.

Hopkins, D.K., Pauly, D., Cruz, E.M. and Van Weerd, J.H., 1982. An alternative to predator-prey ratios in predicting recruitment. Meeresforschung 29, 125-135.

Hussain, M.G., Kohinoor, A.H.M., Islam, M.S.; Hossain, M.A.; Dey, M.M. and Mazid, M.A., 2000. Growth and production performances of gift strain of Nile tilapia, *Oreochromis niloticus* in ponds and cages under different farming conditions in Bangladesh. Journal of Tropical Aquaculture 15, 273-280.

ICLARM, 1998. Dissemination and Evaluation of Genetically Improved Farmed Tilapia Species in Asia: Final Report. International Network on Genetics in Aquaculture. Manila.

Jayaprakas, V., Tave, D. and Smitherman, R.O., 1988. Growth of two strains of *Oreochromis niloticus* and their F1, F2 and backcross hybrids, in: Pullin, R.S.V. , Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture, *ICLARM* Conference Proceedings 15, pp. 623, Department of Fisheries, Bangkok Thailand, and International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 197–201.

Kaufman, L., 1992. Catastrophic change in species-rich freshwater ecosystems the lessons of Lake Victoria. Bioscience 42, 846-858.

Khater, A.A.E., 1985. Identification and comparison of three *Tilapia nilotica* strains for selected aquaculture traits. Doctoral dissertation. Auburn University, Auburn, AL, USA.

Khater, A.A., Smitherman, A.., 1988. Cold tolerance and growth of three strains of *Oreochromis Niloticus*, in: Pullin, R.S.V.,Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, Volume 15. Department of Fisheries, Bangkok Thailand, and International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 215–218.

Khaw, H.L., Ponzoni, R.W. and Danting, M.C., 2008. Estimation of genetic change in the GIFT strain of Nile tilapia (*Oreochromis niloticus*) by comparing contemporary progeny produced by males born in 1991 or in 2003. Aquaculture 275, 64-69.

Kocher, T.D., W.-J. Lee, H. Sobolewska, D. Penman and B. McAndrew 1998. A genetic linkage map of a tilapia (*Oreochromis niloticus*). Genetics 148, 1225-1232.

Li, S.F., Li, C., Dey, M., Gagalac, F. and Dunham, R., 2002. Cold tolerance of three strains of Nile tilapia (*Oreochromis niloticus*) in China. Aquaculture 213, 123-129.

Liti, D., Ekesa, J.B., Munguti, J. and Phelps, R., 2005. Evaluation of growth and reproduction capacity of three strains of Nile tilapia, *Oreochromis niloticus*, found locally in Kenya for use in Aquaculture, in: Burright, J., Flemming, C.,and Egna, H. (Eds.), Twenty-Second Annual Technical Report. Aquaculture CRSP, Oregon State University, Corvallis, Oregon, pp. 327-336.

Longalong, F.M., Eknath, A.E. and Bentsen, H.B., 1999. Response to bidirectional selection for frequency of early maturing females for Nile tilapia (*Oreochromis niloticus*). Aquaculture 178, 13-25.

Lovshin, L.L., De Silva, A.B., 1975. Culture of monosex and hybrid tilapia. FAO/CIFA/75/SR9. Symposium on Aquaculture in Africa. Accra, Ghana, p. 16.

Lovshin, L.L., 1977. Progress Report on Fisheries Development in Northeast Brazil. Research and Development Series, Number 14. International Center for Aquaculture, Agricultural Experiment Station, Auburn University, Auburn, Alabama, p. 11.

Lovshin, L.L., Da Silva, A.B., Carneiro-Sobrinho, A. and Melo, F.R., 1990. Effects of *Oreochromis niloticus* females on the growth and yield of male hybrids (*O. niloticus* female × *O. hornorum* male) cultured in earthen ponds. Aquaculture 88, 55–60.

Lovshin, Leonard L., 2000. Criteria for selecting Nile tilapia and red tilapia for culture, in: Fitzsimmons, K. and Carvalho Filho, J., (Eds.), Tilapia Aquaculture in the 21st CenturyProceedings from the Fifth International Symposium on Tilapia in Aquaculture Volume 1, Ministry of Agriculture, Rio de Janeiro, Brazil, pp. 49–57.

Lutz, Greg C., 2006. Recent Directions In Genetics, in: Tilapia Biology, Culture and Nutrition. Food Products Press an Imprint of Haworth Press Inc. New York.

Macaranas, J. M., Taniguchi, N., Pante, M. J. R., Capili, J. B. and Pullin, R. S. V., 1986. Electrophoretic evidence for extensive hybrid gene introgression into commercial *Oreochromis niloticus* (L.) stocks in the Philippines. Aquaculture and Fisheries Management 17, 249-258.

Macaranas, J.M. and Fujio, Y., 1990. Strain differences in cultured fish – Isozymes and performance traits as indicators. Aquaculture 85, 69-82.

Macaranas, J.M., Mather, P.B., Lal, S.N., Vereivalu, T., Lagibalavu, M. and Capra, M.F., 1997. Genotype and environment: A comparative evaluation of four tilapia stocks in Fiji. Aquaculture 150,11-24.

MacIntosh, D.J. and Little, D.C. , 1995. Nile Tilapia (*Oreochromis niloticus*), in: Bromage, N.R. and Roberts, R.J. (Eds.), Broodstock management and egg and larval quality. Oxgord, U.K.:Blackwell Science, pp. 277-320.

Mair, G.C. and Van Dam, A., 1996. The effect of sex ratio at stocking on growth and recruitment in Nile tilapia (*Oreochromis niloticus*) ponds. in: Pullin, R.S.V., Lazard, J., Legendre, M., Amon Kothias, J.B. and Pauly, D., Editors, 1996. The Third International Symposium on Tilapias in Aquaculture ICLARM Conference Proceedings 41, 100–107.

Marengoni, N.G., Onoue, Y. and Oyama, T., 1998. Offspring growth in a diallel crossbreeding with three strains of Nile tilapia *Oreochromis niloticus*. Journal of the World Aquaculture Society 29, 114-119,

Matricia, T, Talbot, A.J. and Doyle, R.W., 1989. Instantaneous growth rate of tilapia genotypes in undisturbed aquaculture systems "Red" and "grey" morphs in Indonesia. Aquaculture 77, 295-306.

Matricia, T., Talbot, A.J. and Doyle, R.W. 1992. Instantaneous growth rate of tilapia genotypes in undisturbed aquaculture systems: 1. "Red" and "grey" morphs in Indonesia, Aquaculture 77, 295–306.

Mazid, M.A. Hussain, M.G. and Alam, M.J., 1996. Proceedings of a workshop on current status and future strategy for dissemination of genetically improved farmed tilapia in Bangladesh. Fisheries Research Institute, Mymensingh, Bangladesh.

McAndrew, B. J., 1993. Sex Control in Tilapiines, in: Roberts, R.J. and Muir, J. (Eds.), Recent Advances in Aquaculture IV. Blackwell Scientific Publishing, pp. 87-98.

McAndrew, B.J., 2000. Evolution, phylogentic relationships and biogeography, in: Beveridge, M.C.M., McAndrews, B.J. (Eds.), Tilapias: Biology and exploitation. London, England. Kluwer Academic Publisher, pp. 1-32.

McGinty, A.S., 1983. Population dynamics of peacock bass, *Cichla ocellaris* and *Tilapia nilotica* in fertilized ponds. in: Fishelson, L. and Yaron, Z. (Eds.) Proceedings, International Symposium on Tilapia in Aquaculture, 1983. Tel Aviv University Press, Tel Aviv, Israel, pp. 86-94.

McGinty, A.S., 1984. Effects of predation by tucunare (*Cichla ocellaris*) on *Tilapia nilotica* in ponds. The Journal of Agriculture, University of Puerto Rico 68, 101-105.

McGinty, A.S., 1985. Effects of predation by largemouth bass in fish production pods stocked with *Tilapia nilotica*. Aquaculture 46, 269–274.

McIntyre, J.D. and Blanc, J.M. 1973. A genetic analysis of hatching time in steelhead trout *Salmo gairdneri*. J. Fish. Res. Board Can 30, 137–139.

Mires, D., 1988. The inheritance of Black Pigmentation in Two African Strains of *Oreochromis niloticus*, in: Pullin, R.S.V.,Bhukaswan, T., Tonguthai, K. and Maclean, J.L.(Eds.). The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15, 623p. Department of Fisheries, Bankok, Thailand, and Internatioanl Center for Living Aquatic Resources Management, Manila, Philippines.

Nei, M., Maruyama, T. and Chakraborty, R., 1975. The bottleneck effect and genetic variability in populations. Evolution 29, 1-10.

Ng, Wing-Keong and Hanim, Rosdiana, 2007. Performance of genetically improved Nile tilapia compared with red hybrid tilapia fed diets containing two protein levels. Aquaculture Research 38, 965-972.

Osure, G.O. and Phelps, R.P., 2006. Evaluation of Reproductive Performance and Early Growth of Four Strains of Nile Tilapia, *Oreochromis niloticus*, with Different Histories of Domestication. Aquaculture 253, 485-494.

Payne, A.I., 1983. Esturine and salt tolerant tilapias, in: Fishelson, L. and Yaron, Z. (Eds.), Proceedings of the International Symposium on Tilapia in Aquaculture, Nazareth, Israel, Tel Aviv, Israel: Tel Aviv University, pp. 534-543.

Penman, D.J. and McAndrew, B.J., 2000. Genetics for the management and improvement of cultured tilapias, in: Beveridge, M.C.M. and McAndrew, B.J. (Eds.),Tilapias: Biology and Exploitation. Fisheries Series 25 Kluwer, Dordrecht, The Netherlands, pp. 227-226.

Phillippart, J.C. and Ruwet, J.C., 1982. Ecology and distribution of tilapias, in: Pullin, R.S.V., Lowe-McConnell, R.H. (Eds.), The biology and culture of tilapias. Manila Philippines: ICLARM Conference Proceedings 7, pp. 15-59.

Ponzoni, R.W., Hamzah, A., Tan S. and Kamaruzzaman, N., 2005. Genetic parameters and response to selection for live weight in the GIFT strain of Nile tilapia, *Oreochromis niloticus*. Aquaculture 247, 203–210.

Popma, T.J. and Rodriquez, F.B., 2000. Tilapia aquaculture in Colombia, in: Costa-Pierce, B.A., Rakocy, J.E, (Eds.), Tilapia Aquaculture in the Americas. Volume 2. Baton Rouge, Louisiana: The World Aquaculture Society, pp. 141-150.

Pullin, R.S.V., Capili, J.B., 1988. Genetic improvement of tilapias: problems and prospects, in: Pullin, R.S.V., Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, Volume 15. Department of Fisheries, Bangkok Thailand, and International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 259–266

Rakocy, James E. 1989. Tank culture of tilapia. Southern Regional Aquaculture Center Publication Number 282.

Ramos-Henao, A. and Corredor, G.G., 1980. Effects of three management practices on the growth and production of *Tilapia rendalli*. Bamidgeh 32, 41-45.

Ridha, Mohammad T. 2006. Comparative study of growth performance of three strains of Nile tilapia, *Oreochromis niloticus* at two stocking densities. Aquaculture Research 37, 172-179.

Romana-Eguia, M.R.R. and Doyle, R.W., 1992. Genotype-environment interaction in the response of three strains of Nile tilapia to poor nutrition. Aquaculture 108, l- 12.

Romana-Eguia, M.R.R. and Eguia, R.V., 1999. Growth of five Asian red tilapia strains in saline environments. Aquaculture 173, 161-170.

Ruwet, J.C., Voss, J., Hanon, L. and Micha, J.C., 1976. Biologie et élévage des Tilapias, in: Symp.sur l'aquaculture en afrique. CIFA Technical paper. Number 4, pp. 331–359.

Schroeder, G. L., 1978. Autotrophic and heterotrophic production of microorganisms in intensely manured fish ponds and related fish yields. Aquaculture 14, pp. 303-305.

Shelton, W.L., and Popma, T.J. 2006. Biology, in: Lim, C., Webster, C. D. (Eds.), Tilapia Biology, Culture and Nutrition. Food Products Press an Imprint of Haworth Press Inc. New York, pp. 1-27.

Sifa, L., Chenhong, L., Dey, M., and Dunham, R., 1999. Seinability of four strains of Nile Tilapia (*Oreochromis niloticus*,) in Chinese ponds. Aquaculture 174, 223-227.

Smitherman, R.O. and Tave, D., 1987. Maintenance of genetic quality in cultured tilapia. Asian Fisheries Science 1, 75-82.

Stickney, R.R. 1986. Tilapia tolerance of saline waters: a review. Progressive Fish Culturist 48, 161-167.

Swingle, H.S., 1966. Biological means of increasing productivity in ponds. FAO Fisheries Report 44, 243-257.

Tave, D. 1986. Genetics for Fish Hatchery Managers. AVI Publishing, Wesport, CT, USA.

Tave, D. and Smitherman, R.O., 1980. Predicted Response to Selection for Early Growth in *Tilapia nilotica*. Transactions of the American Fisheries Society 109, 439-445.

Tayamen, M.M., Abella, T.A. and Sevilleja, R.C., 2006. The role of public sector in dissemination of tilapia genetics research outputs and links with private sector, in: Acosta, B.O., Sevilleja, R.C. and Gupta, M.V. (Eds.), Public and private partnerships in aquaculture: a case study on tilapia research and development. WorldFish Center Conference Proceedings 72, p. 16 – 20.

Teichert-Coddington, D.R. and Green, B.W., 1997. Experimental and commercial culture of Tilapia in Honduras, in: Costa-Pierce, B.A. , Rakocy, J.E. (Eds.), Tilapia Aquaculture in the Americas Volume 1, Baton Rouge, Louisiana: The World Aquaculture Society, pp. 142–162.

Teichert-Coddington, D. R. and Smitherman, R. O., 1988. Lack of response by *Tilapia nilotica* to mass selection for rapid early growth. Transactions of the American Fisheries Society 117, 297-300.

Thurston, R.V., Russo, R.C. and Emerson, K. 1974 Aqueous ammonia equilibrium calculations. Technical Report 74-1. Fisheries Bioassay Laboratory, Montana State University, Bozeman, Montana.

Toguyeni, A., Fauconneau, B, Fostier, A., Abucay, J., Mair, G. and Baroiller, J.F., 2002. Influence of sexual phenotype and genotype, and sex ratio on growth performance in Tilapia (*Oreochromis niloticus*). Aquaculture 207, 249-261.

Trewavas, E., 1983. Tilapiine fishes of the genera *Sarotherodon, Oreochromis* and *Danakilia.* Cornell Itahaca, NY: University Press.

Uraiwan, S. 1988. Direct and indirect responses to selection for age at first maturation of *Oreochromis niloticus*, in: Pullin, R.S.V., Bhukaswan, T., Tonguthai, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. Department of Fisheries, ICLARM, Bangkok Thailand. pp. 295-300.

Uraiwan, S. and Phanitchai, V., 1986. A study of strain selection of *Tilapia nilotica.* Aquaculture 57, 376-377.

Watanabe, W.O., Losordo, T.M., Fitzsimmons, K. and Hanley, F., 2002. Tilapia Production Systems in the Americas: Technological Advances, Trends, and Challenges. Reviews in Fisheries Science 10, 465-498.

Wohlfarth, G.W. and Hulata, G., 1983. Applied genetics of tilapias. ICLARM Studies and Reviews 6 (2^{nd} edition). International Center for Living Aquatic Resources Management, Manila, Philippines.

Wootten, R.J., 1990. Ecology of teleost fishes. London:Chapman and Hall.

Wright, S., 1931. Evolution in Mendelian populations. Genetics 28, 114-138.

CHAPTER 4

EVALUATION OF PROCESSING CHARATERISTICS OF FOUR STRAINS OF NILE TILAPIA *Oreochromis niloticus* AND A RED VARIETY CULTURED IN AN OUTDOOR INTENSIVE STATIC SYSTEM

Abstract

Tilapia (*Oreochromis, spp.*) have been introduced globally and domesticated resulting in a number of different strains. This diversity offers the potential for difference in body morphology and in turn fillet yields. A trial was conducted at Auburn University, Auburn, AL, USA to compare processing characteristics of four populations of *Oreochromis niloticus* using two domesticated strains (Egypt and Ivory Coast) and two less domesticated strains (Sagana and Lake Victoria). In addition, a red variety of tilapia (Santa Fe) was also evaluated.

Male tilapia (n= 25/strain) were manually processed and percent dressout and visceral fat were calculated. Mean individual weights of pre-processed fish were similar (Range = 403.8 ± 27.6g to 413.8 ± 24.5g) with the exception of the larger Sagana strain (434.2 ± 15.4g). The Ivory Coast strain had the highest percent dress-out (33.1 ± 2.1%) while Sagana strain had the lowest (29.6 ± 1.5%). The Red strain had the greatest percent visceral fat (2.3 ± 1.0%) and the Sagana had the lowest (0.2 ± 0.4%).

Introduction

Tilapia have rapidly become one of the most popular freshwater fish purchased in U.S. markets (170,373 metric tons) (USDOC, 2010). A significant portion of this consumption is as fillets (137,740 metric tons) (USDOC, 2010). Among commercial aquaculture species, tilapia is difficult to process and has a relatively low fillet yield (Snir, 2001). Rutten et al., (2004) reported Nile tilapia fillet yields of 34.4 % for Chitralda strain, 35% for International Development Research Center (IDRC) strain and 38% for genetically improved farm tilapia (GIFT) strain for fish manually processed with a pre-processed weight of 700 g/fish. Clement and Lovell (1994) reported fillet yields of 25.4% from manually processed Nile tilapia, *O. niloticus* (585 g/fish). Fillet yield of other freshwater species have been as high as 52.7-53% for manually processed 255-267g rainbow trout *Oncorhynchus mykiss* (Rasmussen and Ostenfeld, 2000). Other freshwater fish give fillet yields of: 45.7%, *Ictalurus punctatus* x *Ictalurus furcatus* (Argue et al., 2003), 44.4% for blue catfish, *Ictalurus furcatus* (Argue et al., 2003), 42.5 % for channel catfish, *Ictalurus punctatus* (Argue et al., 2003), 36.8% for palmetto bass, *Morone saxatilis* x *Morone chrysops* (Bosworth et al., 1998), 36.7%, paradise bass, *Morone saxatilis* x *Morone mississippiensis* (Bosworth et al., 1998) and 31%, common carp, *Cyprinus carpio* (Cibert et al., 1999).

Filleting yield depends on machinery efficiency, operator experience, fish shape and filleting method (El-Sayed, 2006). Popma and Lovshin (1995) report that tilapia fillets that have the ribs removed but retain some flesh from the rib cage and the pin bones yield about 36 to 38 % of total live weight. The same fillet, with a triangular notch on the median line to remove the pin bones, yields about 32 to 35 % of live weight. Fillets with pin bones and rib cage flesh removed, so that only the tenderloin and caudal area remain, yield 28 to 31% of live weight.

Some large tilapia are "deep skinned " to remove some of the red muscle found under the skin. Deep skinning reduces the filet yield to 22 to 25% of the live weight. Souza and Macedo-Viegas (2000) evaluated the effects of four different filleting methods on the processing yield of Nile tilapia in Brazil. The filleting methods were: (i) skinning and filleting the whole fish; (ii) filleting the whole fish and then removing the skin, (iii) skinning and filleting headless fish; and (iv) filleting headless fish and then removing the skin. The best fillets and total eatable yield (36.59 and 42.15 %, respectfully) were obtained with skinning the whole fish before filleting, followed by filleting and skinning headless fish. Skinning and filleting the whole fish also produced thicker and longer fillets compared to the other methods. The type of head cut used during processing also affects the dressout and yield of tilapia (Souza et al., 2000). The authors found that contour and oblique head cuts produced better dressout and yield than straight head cuts.

Studies into alternative strategies for the improvement of fillet yield in fish have mainly concentrated on the use of body measurements as selection-criteria related to fillet yield (Bosworth et al., 1998; Bosworth et al., 2001; Cibert et al., 1999), but the results from these studies were only moderately positive. One main conclusion has been that the correlation between body weight and fillet weight is generally high and the correlation between body weight and percent fillet yield is generally low (Bosworth et al., 1998; Cibert et al., 1999). Body measurements of fish have been the traits of interest in these studies mostly because they are descriptive with respect to the shape of an animal. The shape of an animal is not only directly related to its weight, but also to fillet yield of fish (Bosworth et al., 1998, Bosworth et al., 2001; Cibert et al., 1999). Furthermore, Rutten et al. (2005) reported on slaughter data collected from 1,884 pedigreed Nile tilapias, that genetic correlation between fillet weight and body

measurements was 0.89 for length, 0.70 for head length, 0.94 for width and 0.91 for corrected length. In addition, this author reported that genetic correlation between fillet yield and body measurements was 0.62 for length, 0.47 for head length and 0.98 for width.

The primary focus of this study was to compare processing characteristics of four strains of Nile tilapia and a red variety (Santa Fe). The four populations of Nile tilapia included two established domesticated lines (Egypt and Ivory Coast) and two less domesticated lines (Sagana and Lake Victoria).

Materials and Method

Four strains of Nile tilapia and a red variety of varying geographical origins and domestication histories were used. Ivory Coast strain was established at Auburn in 1974 from a batch of 100 fish from Fortaleza, Brazil (Lovshin and De Silva, 1975). Ancestors of the strain (100–200 fish) were introduced to Fortaleza from Bouake, Ivory Coast in 1971 (Lovshin and De Silva, 1975). The stock at Bouake, Ivory Coast, was from the tributaries of the Niger and Lake Volta (Trewavas, 1983). Egypt strain of Nile tilapia was collected from the Ismailia canal of the Nile River, about 75 km northeast of Cairo, with 20 males and 66 females introduced to Auburn University in May, 1982 (Khater, 1985). Sagana and Lake Victoria strains were introduced to Auburn University in March 2002 from Kenya (Osure and Phelps, 2006). The Sagana strain originated from Lake Turkana. It was introduced to Baobab farm, Kenya in the early 1980's and then introduced to Sagana Fisheries Research Station, Sagana Kenya in 1994 (Trewavas, 1983). This subspecies was classified by Trewavas (1983) as *Oreochromis niloticus vulcani*. The Auburn University stock was founded from 35 fingerlings with an average weight of 45 g (Osure and Phelps, 2006). Fish of the Lake Victoria strain were the first generation offspring of brood

stock introduced to the Sagana Fisheries Research Station four months prior from Lake Victoria. The Auburn population was established from 240 fry (age = 3 weeks). The Auburn University stock of the red variety (Santa Fe strain) was established from 136 individuals. They were obtained in August of 2000 from Colombia, South America. Ivory Coast and Egypt strains were considered highly domesticated strains while the Sagana and Lake Victoria were considered less domesticated for comparison of production characteristics herein.

The grow-out culture trial was conducted outdoors in 12 m^3 (mean depth = 0.6 m) concrete tanks from May 30, 2007 through September 27, 2007 to compare production characteristics of five stocks. The water source was screened (nylon mesh) surface water harvested from a forested watershed held in an 8.1 ha reservoir. Water was exchanged (50% by volume) in each tank when concentrations of unionized ammonia were >1 mg/L or nitrite levels were >1 mg/L. Aeration was provided by a Sweetwater (1 h.p.) regenerative air blower at an average of 3000 cm^3/sec/tank using 3 m of 2.5 cm diameter generic diffuser hose. The tanks were stocked with hand-sexed male tilapia (94-98 g) at 3 fish/m^2 density. There were four replicates per treatment. The fish were fed a commercial 36% protein floating pellet (3 mm) (Cargill) twice daily to satiation. Production results are given in Chapter 3.

The fish were pooled (by strain) from the previous study (See Chapter 3). Male tilapia (n = 25 fish/strain) were individually weighed (414 ± 12g) and processed. There was no length measurements recorded prior to processing. Lengths of fish were recorded at harvest (n = 80 fish/strain). Therefore, a sample (n=25 fish/strain) of fish with similar size range (416 ± 22 g) from this data set were used to calculate condition factors (K) were calculated with the following formla: $K = \{(\text{total weight (g)} / \text{total length}^3 \text{ (cm)}) \times 100\}$ (Hassan et al., 2008; Valentim-Zabott et al., 2008).

Fish were collected during the final harvest of the outdoor experiment and held on ice 2 ± 0.25 hrs before being processed. Fish (6-7 fish/processor) were manually processed by station staff. Each processor (n= 4) were evaluated to insure similar processing proficiency. Weight data (± 0.1g) was collected to generate percent of dress-out and visceral fat. Each fish was weighed, de-headed, gutted, and visceral fat removed and weighed. The processors inserted a fillet knife along the dorsal fin downwards toward the anal fin and the fillet and skin flipped over. The knife was inserted between the fillet and skin and manipulated to liberate the fillet. Intramuscular bones in the fillet were removed. Percent dress-out was calculated as fillet weight / whole body weight x 100. Fillet weight was recorded as the combined weight of two fillets from the respective fish processed. Percent visceral fat was calculated as total visceral fat / whole fish weight x 100.

Statistical analyses were performed using SAS (SAS Institute Inc., SAS 9.1.3, Cary, NC: SAS Institute Inc., 2000-2004.). Data from experiments were analyzed using the analysis of variance (ANOVA) F-test to determine if there were significant differences (P=0.05) among parameters. When assumptions for ANOVA were violated the Kruskal-Wallis nonparametric test of ranked sums was used. Fisher's least significant difference (LSD), Tukey's honest significant difference (HSD), Scheffe's and Bonferroni-Dunn tests were used as the post hoc tests to determine where the differences were among the strains. Regression analysis was used to model significant differences.

Results

Evaluation of processor efficiency showed that there were no differences in three of the four individuals (Table 1) ($P = 0.27$). Therefore, samples from the processor with different ($P < 0.0001$) results were omitted from the analysis resulting in 20 fish being processed by strain. Significant differences were found among all parameter means in the fish processing trial (Table 2). Mean (±SD) individual weights (Range = 403.8 ± 27.6g to 413.8 ± 24.5g) of pre-processed fish were similar with the exception of the larger Sagana strain (434.2 ± 15.4g). The Red strain had the highest (2.01 ± 0.17) condition (K) and the Sagana strain the lowest (1.74 ± 0.09) ($P \leq 0.001$). The Ivory Coast strain had the highest percent dress-out (33.1 ± 2.1%) and Sagana strain had the lowest (29.6 ± 1.5%) ($P < 0.0001$). The Red strain had the greatest mean percent visceral fat (2.3 ± 1.0%) and the Sagana had the lowest (0.2 ± 0.4%) ($P < 0.0001$).

Discussion

There have been few studies focusing on the fish processing characteristics of tilapia. Even fewer have focused on processing differences among strains. In this trial, hand-sexed males of four strains of *O. niloticus* (Egypt, Ivory Coast, Lake Victoria and Sagana) and one red strain (Santa Fe) cultured under similar conditions gave different fillet yields.

Skill level of filleter can impact fillet yield. In this study, one filleter (omitted from analysis) obtained fillet yields 7.7 % less than the average of the others. The difference in fillet yield among the other filleters was 0.8%. Ribeiro et al. (1998) found that fillet yield of red tilapia varied approximately 3.3% between filleter.

The Ivory Coast strain demonstrated the highest percent dress-out (33.1 ± 2.1%) and the Sagana strain had the lowest (29.6 ± 1.5%) using fish weighing 414 ± 12g. These dress-out

percentages are higher than ones (25 %) described by Clement and Lovell (1994) and are similar to the results described by Garduno et al. (2003) for Nile tilapia (32%) and Red tilapia (33.4%). However, they are not as high as the Chitralada Nile strain (34.4 %) reported by Rutten et al. (2004) or the GIFT strain (38 %) by Bestari (2004).

The amount of visceral fat varied among the strains with the red (2.3 ± 0.1%) having almost twice that of any other strain (Table 2). This was interesting since all treatments were fed to satiation on a commercial feed. No red tilapia fingerlings were harvested while up to 15.5 ± 10.4 % of the final standing crop was as fingerlings in the Nile strains (Chapter 3; Table 7). Brummett (2002) compared gross yield among three typical tilapia production systems in Africa. He found that a large number of juveniles would over-exploit the food resource base and that a reduction in juvenile density had the largest impact on increasing yield. Survival among Red tilapia was significantly ($P = 0.004$) lower than that of the Nile strains (Chapter 3; Table 7) contributing to lower density that made food items more readily available. According to Schroeder (1978), natural food organisms typically account for 30 to 50% of tilapia growth in intensive culture ponds with heavy feeding. Cho and Jo (2002) conducted feeding trials to determine the combined effect of dietary energy levels and number of daily meals on growth and body composition in Nile tilapia. They found that visceral fat content was significantly affected by dietary energy levels. Representative assimilation efficiencies (quantity assimilated as a percentage of the quantity ingested) for fish are: invertebrate protein and energy, 80% (Persson, 1983); algal protein, 85% and energy, 70% (Moriarty, 1973; Kitchell et al., 1978; Wessel et al., 1982; Teferra, 1988) and detritus protein, 77% and energy, 63% (Bowen, 1979, 1981). Boyd (1985) reported chemical budgets for pond culture of channel catfish (*Ictalurus punctatus*). He reported that only a small portion of nitrogen (26.8%), phosphorus (30.1%) and organic matter

(25.5%) applied to the ponds as feed is harvested in fish flesh. Acosta-Nasser et al. (1994) reported nitrogen budgets for the freshwater pond production of hybrid *Oreochromis* and found that commercial sized fish only accumulated 17.5% of the nitrogen added to the system. Therefore, reduced competition from juveniles, lower density and dietary energy levels may explain the higher percent visceral fat content of the Red tilapia.

Fillet yield ($R^2 = 0.02$) and percent visceral fat ($R^2 = 0.008$) were not correlated with fish body weight. The percent fillet yield did not vary significantly over the size range of fish (369-470g) examined. Fillet yields have been reported to vary with fish size by several authors (Bosworth et al., 1998; Cibert et al., 1999; Kirkup et al., 2004; Ruten et al., 2004; Nguyen et al., 2010). Red tilapia fillet yield were compared by Ribeiro et al. (1998) for fish of four size classes 150-350 g; 351-550 g; 551-750 g; and, 751-950 g. They found no difference in fillet yield until the fish were over 751 g. They did find a correlation of fillet yield to body width than body weight.

The five strains differed in percent fillet yields as well as production characteristics. The Sagana strain gave a greater yield/kg than the other strains (Chapter 3) but had the lowest percent dressout. However, when viewed from the perspective of selecting a strain to produce fillets for commercial markets the Sagana strain gave the highest fillet yield (3,803 kg/ha) while the next highest were Egypt and Ivory Coast (3,593 and 3,562 kg/ha respectively). Assuming a fillet value of $4.00/kg, this translates to a difference of $837 to $963/ha between the Sagana strain and the next best producing strain.

Conclusion

Fillet yields will vary among strains of tilapia and may be influenced by the individual filleter but not the percent visceral fat or fish size. Fillet yield should not only be viewed as the percent yield but also include the productivity of the fish (kg/ha). The Sagana strain gave the lowest percent body weight fillet yield but also produced the greatest yield of fillets/ha.

Table 1
Mean (±SD) efficiency score (% fillet dress-out) for fish (n= 25 fish /strain; 20 fish/strain) processors (n=4) evaluated by percent fillet yield from whole tilapia held on ice 2 ± 0.25 hrs prior to processing.

Processor #	**Processor (n= 4)** **(% fillet dress-out)**	**Processor (n= 3)** **(% fillet dress-out)**
1	31.5 ± 2.3[a]	31.5 ± 2.3
2	31.6 ± 2.0[a]	31.6 ± 2.0
3	30.8 ± 2.4[a]	30.8 ± 2.4
4	28.9 ± 2.1[b]	omitted
P-Value	0.0001	0.2648

Table 2
Mean (±SD) for preprocessed fish weight (g), condition (K), fillet yield (%) and visceral fat (%) processing results by strain from a static outdoor production system where tilapia were stocked at 2 fish/m^2 and fed a commercially available diet of 36% protein floating pellets for 120 days.

Strain	**Fish weight (g)**	**Condition(K)**	**Fillet Yield (%)**	**Visceral Fat (%)**
Egypt	413.8 ± 24.5^{a}	1.84 ± 0.09^{b}	30.8 ± 1.7^{a}	1.2 ± 2.5^{a}
Ivory Coast	406.7 ± 19.8^{a}	1.91 ± 0.12^{ab}	33.1 ± 2.1^{b}	1.2 ± 0.4^{a}
Lake Victoria	403.8 ± 27.6^{a}	1.84 ± 0.11^{b}	31.8 ± 1.9^{ab}	1.2 ± 0.8^{a}
Sagana	434.2 ± 15.4^{b}	1.74 ± 0.09^{c}	29.6 ± 1.5^{c}	0.2 ± 0.4^{b}
Red	411.2 ± 20.5^{a}	2.01 ± 0.17^{a}	31.3 ± 2.4^{a}	2.3 ± 1.0^{c}
P-Value	0.001	0.000	0.000	0.000

References

Acosta-Nassar, M.V., Morell, J.M. and Corredor, J.E., 1994. The nitrogen budget of a tropical semi-intensive freshwater fish culture pond. Journal of the World Aquaculture Society 25, 261-270.

Argue, B.J., Liu, Z., Dunham, R.A., 2003. Dress-out and fillet yields of channel catfish, *Ictalurus punctatus*, blue catfish, *Ictalurus furcatus,* and their F_1, F_2 and backcross hybrids. Aquaculture 228, 81-90.

Bestari, Njoman, 2004. An Impact Evaluation of Genetically Improved Farmed Tilapia and Their Dissemination in Developing Countries. Operations Evaluations Department. Asian National Bank. IES:Reeg 2004-20.

Bosworth, B.G., Libey G.S., and Notter, D.R., 1998. Relationships among body weight, body shape, visceral components, and fillet traits in palmetto bass (striped bass female *Morone saxatilis*×white bass male *M. chrysops*) and paradise bass (striped bass female *M. saxatilis*×yellow bass male *M. mississippiensis*). Journal of the World Aquaculture Society 29, 40–50.

Bosworth, B.G., Holland, M. and Brazil, B.M., 2001. Evaluation of ultrasound imagery and body shape to predict carcass and fillet yield in farm-raised catfish. Journal of Animal Science 79, 1483–1490.

Bowen, S.H., 1979. A nutritional constraint in detritivory by fishes: the stunted population of *Sarotherodon mossambicus* in Lake Sibaya, South Africa. Ecological Monographs 49, 17-31.

Bowen, S.H., 1981. Digestion and assimilation of periphytic detrital aggregate by *Tilapia mossambica*. Transactions of the American Fisheries Society 100, 2239-2245.

Boyd, C.E., 1985. Chemical budgets for channel catfish ponds. Transactions of the Amercian Fisheries society 114,291-298.

Brummett, R.E., 2002. Comparison of African tilapia partial harvesting systems. Aquaculture 214, 103-114.

Cho, S.H. and Jo, J.Y. 2002. Effects of dietary energy level and number of meals on growth and body composition of Nile tilapia Oreochromis niloticus during summer and winter seasons. Journal of the World Aquaculture Society 33, 48-56.

Cibert,C., Fermon, Y., Vallod, D. and Meunier, F.J., 1999. Morphological screening of carp *Cyprinus carpio*: relationship between morphology and fillet yield. Journal of Aquatic Living Resources 12, 1–10.

Clement, S. and Lovell, R.T., 1994. Comparison of processing yields and nutrient composition of cultured Nile tilapia (*Oreochromis niloticus*) and channel catfish (*Ictalurus punctatus*). Aquaculture 119, 299-310.

El-Sayed, Abdel-Fattah, 2006. Tilapia Culture. CABI Publishing, Cambridge, MA, USA.

Garduno-Lugo, M., Granados-Alvarez, I., Olvera-Novoa, M. and Munoz-Cordova, G., 2003. Comparison of growth, fillet yield and proximate composition between Stirling Nile tilapia (wild tye)(*Oreochromis niloticus*) and red hybrid tilapia (Florida red tilapia x Stirling red *O. niloticus*) males. Aquaculture Research 31, 1023-1028.

Gupta, M. V., and Acosta, B. O., 2004. A review of global tilapia farming practices. Aquaculture Asia, published by NACA (National Aquaculture Centers in Asia- Pacific), pp. 7-12.

Hassan, A.S., Sayed, S.H. and Ibrahim, E.M., 2008. Effects of stocking rates and supplementary feed on the growth performance of Blue Tilapia (*Oreochromis aureus*) and grass carp (*Ctenopharyngodon idella*) reared in earthen ponds. Eighth International Symposium on Tilapia in Aquaculture. Central Laboratory for Aquaculture Research, Egypt.

Khater, A.A.E. ,1985. Identification and comparison of three Tilapia nilotica strains for selected aquacultural traits. Auburn University, Alabama, USA, Ph.D. dissertation.

Khater, A.A., Smitherman, A., 1988. Cold tolerance and growth of three strains of *Oreochromis niloticus*, in: Pullin, R.S.V., Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, vol. 15. Department of Fisheries, Bangkok Thailand, and International Centre for Living Aquatic Resources Management, Manila, Philippines, pp. 215–218.

Kirkup, S.P., Marsh, L.S., and Coale, C.W., 2004. Skinless v-notched fillet yields of Tilapia (*Oreochromis*). International Journal of Recirculating Aquaculture 5, pp.19-27.

Kitchell, J.F., Stein, R.A. and Knezevic, B., 1978. Utilization of filamentous algae by fishes in Skadar Lake, Yugoslavia. Internationale Vereinigung fur theoretische und angewandte Limnologie, Verhandlungen 20, 2159-2165.

Lovshin, L.L., De Silva, A.B., 1975. Culture of monosex and hybrid tilapia. FAO/CIFA/75/SR9. Symposium on Aquaculture in Africa. Accra, Ghana, p. 16.

Maar, A., Mortimer, M.A.E. and Van der Lingen, I., 1966. Fish culture in Central East Africa. FAO Corporate Document Number 20. Rome, Italy: Food and Agriculture Organization of the United Nations.

MacIntosh, D.J. and Little, D.C. , 1995. Nile Tilapia (*Oreochromis niloticus*), in: Bromage, N.R., Roberts, R.J. (Eds.), Broodstock management and egg and larval quality. Oxford, U.K.: Blackwell Science, pp. 277-320.

McAndrew, B.J., 2000. Evolution, phylogentic relationships and biogeography, in: Beveridge, M.C.M., McAndrews, B.J. (Eds.), Tilapias: Biology and exploitation. London, England. Kluwer Academic Publisher, pp.1-32.

Moriarty, D.J.W., 1973. The physiology of digestion of bluegreen algae in the cichlid fish, *Tilapia nilotica*. Journal of Zoology, London, 171, 25-39.

Nguyen, N.H., Ponzoni, R.W. Abu-Bakar, K.R. Hamzah, A., Khaw, H.L. and Hong, Y. 2010. Correlated reponse in fillet weight and yield to selection for increased harvest weight in genetically improved farmed tilapia (GIFT strain) *Oreochromis niloticus*. Aquaculture 305, 1-5.

Osure, G.O. and Phelps, R.P., 2006. Evaluation of Reproductive Performance and Early Growth of Four Strains of Nile Tilapia (*Oreochromis niloticus*) with Different Histories of Domestication. Aquaculture 253, 485-494.

Persson, L., 1983. Food consumption and the significance of detritus and algae to intraspecific competition in roach *Rutilus rutilus* in a shallow eutrophic lake. Oikos 41, 118-125.

Phillippart, J-Cl. Ruwet, J., 1982. Ecology and distribution of tilapias, in: Pullin, R.S.V. , Lowe-McConnell, R.H. (Eds.), The biology and culture of tilapias. Manila Philippines: ICLARM Conference Proceedings 7, pp. 15-59.

Popma, T.J. and Lovshin, L.L., 1995. Worldwide prospects for commercial production of tilapia. International Center for Aquaculture and Aquatic Environments. Department of Fisheries and Allied Aquacultures. Auburn University, Alabama.

Pullin, R.S.V. and Capili, J.B., 1988. Genetic improvement of tilapias: problems and prospects, in: Pullin, R.S.V., Bhukaswan, T., Tonguthayi, K., Maclean, J.L. (Eds.), The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings, Volume 15. Department of Fisheries, Bangkok Thailand, and ICLARM, Manila, Philippines, pp. 259–266

Rasmussen, R.S. and Ostenfeld, T.H., 2000. Effect of growth rate on quality traits and feed utilization of rainbow trout, *Oncorhynchus mykiss*, and brook trout, *Salvelinus fontinalis*. Aquaculture 184, 327-337.

Ribeiro, L. P.; Lima, L. C.; Turra, E. M.; Ribeiro, T. G.Q.; Miranda, M. O. T.,1998. Efeito do peso e do operador sobreo rendimento de filé em tilápia vermelha, *Oreochromis spp*.in*:* Aquicultura Brasil'98, 2, 773-778.

Rutten, M., Bovenhuis, H. and Komen, H., 2004. Modeling fillet traits based on body measurements in three Nile tilapia strains (*Oreochromis niloticus*). Aquaculture 231, 113-122.

Rutten, M., Bovenhuis, H., and Komen, H., 2005. Genetic parameters for fillet traits and body measurements in Nile tilapia, *Oreochromis niloticus*. Aquaculture 246, 125-132.

Shelton, W.L., and Popma, T.J. 2006. Biology, in: Lim, C., Webster, C. D. (Eds.), Tilapia Biology, Culture and Nutrition. Haworth Press Inc. New York, pp. 1-27.

Snir, I.J., 2001. Value added tilapia products: deliberate policy or no other choice, in: Subasinghe, S., Singh, T. (Eds.), Tilapia: Production, Marketing and Technological Developments. Proceedings of the Tilapia 2001 International Technical and Trade Conference on Tilapia. Infofish, Kulala Lumpur, Malaysia, p. 84.

Souza, M.L.R., and Macedo-Viegas, E.M., 2000. Effects of filleting on processing yield of Nile tilapia, *Oreochromis niloticus,* in: Fitzsimmons, K., Filho, J.C. (Eds.), Tilapia Culture in the 21st Century. Proceedings from the fifth International Symposium on tilapia Aquaculture, Rio de Janeiro, Brazil. American Tilapia Association, Charlestown, West Virginia, and ICLARM, Penang, Malaysia, pp. 451-457.

Souza, M.L.R., Marengoni, N.G., Pinto, A.A. and Cacador, W.C., 2000. Processing yield of Nile tilapia , *Oreochromis niloticus,*: head cut types and two weight classes. Acta Scientiarium 22, 701-706.

Teferra, G., 1988. Digestive efficiency and nutrient composition gradient in the gut of *Oreochromis niloticus* in Lake Awassa, Ethiopia. Journal of Fish Biology 33, 501-509.

Trewavas, E., 1983. Tilapiine fishes of the genera *Sarotherodon, Oreochromis* and *Danakilia.* Cornell Itahaca, NY: University Press.

United States Department of Commerce Bureau of Census. 2010. http://www.ers.usda.gov/data/aquaculture/Tables/Tilapia_V_Yearly.pdf

Watanabe, W.O., Losordo, T.M., Fitzsimmons, K. and Hanley, F., 2002. Tilapia Production Systems in the Americas: Technological Advances, Trends, and Challenges. Reviews in Fisheries Science 10, 465-498.

Wessel, B., Spittler, P. and Heerkloss, R., 1982. Untersuchungen zur Nahrungsverwertung vorgestericker Silberkarpfen (*Hypophthaalmichthys molitrix*) mittels doppelt markierter Algen (C14 and Cr51). Naturwissenschaftliche Reihe 6, 43-44.

Valentim-Zabott, M., Vargas, L., Ribeiro, R.P.R., Piau Jr., R., Torres, M.B.A., Ronnau, M. and Souza, J.C., 2008. Effects of a homeopathic complex in Nile tilapia (*Oreochromis niloticus*) on performance, sexual proportion and histology. Homeopathy 97, 190-195.

Xia, D.Q., 2000. The current status of tilapia culture and prospects in China. Scientific Fish Farming 5, 1-2.

SUMMARY

Among the strains evaluated under the intensive indoor and outdoor culture conditions of this research station, no one strain or domestication status demonstrated a distinct production advantage. However, there was a positive production advantage of the Nile strains over the Red variety in the intensive outdoor culture system. The Sagana strain demonstrated the highest fillet yield per hectare.