COMPARISON OF GROWTH AND PRODUCTION OF INDIGENIOUS STRAINS OF THE MOZAMBIQUE TILAPIA, *OREOCHROMIS MOSSAMBICUS* (PETERS)

by

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DECLARATION

I declare that the dissertation hereby submitted to the University of Limpopo for the degree of Master of Science in Aquaculture in the Faculty of Sciences, Health and Agriculture has not previously been submitted by me for a degree at this or any other University, that it is my own work in design and in execution, and that all material contained therein has been fully acknowledged.

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Content overview page

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Abstract

The aquaculture potential of the following four purebred strains of the Mozambique tilapia, *Oreochromis mossambicus*, was evaluated: Red, Seshego, Venda and Zulu strains. Studies comparing the fry production potential, growth during the nursery phase and growth during the grow-out phase were undertaken. Three strains are named according to their place of origin, whilst the Red strain was named according to its body colour.

The four different strains investigated showed different responses during the aquacultural production phases i.e. fry production, nursery phase and grow-out phase. After spawning, the Zulu strain produced the largest number of fry (8 825), followed by the Venda (7 500), Seshego (5 625) and the Red strain (3 300), with the lowest number of fry. In terms of the mean mass at harvest during the nursery phase, the Venda strain (7.2 ± 5.0 g, 8.9 ± 5.0 g) seems to perform best followed by either the Zulu (4.9 ± 4.2 g, 4.8 ± 3.9 g) or Seshego (4.8 ± 4.2 g, 4.3 ± 3.9 g) strain for the aquaria and tanks respectively. The Red strain had the lowest mass at harvest (4.0 ± 2.7 g, 3.3 ± 1.5 g) for the aquaria and tanks respectively. The mean mass at harvest after the grow-out phase was highest for the Zulu strain (80.0 ± 24.0 g, 44.4 ± 31.5 g) followed by either the Venda strain (70.2 ± 31.5 g, 40.7 ± 15.7 g) or Seshego (67.1 ± 28.1 g, 38.4 ± 11.1 g) for the recirculating system and semi-intensive system respectively. The Red strain had the lowest mass at harvest (60.6 ± 16.5 g, 37.0 ± 9.9 g) for fish raised in a recirculating system and semi-intensive system (dome ponds) respectively. Males were found to be significantly bigger than females i.e. Zulu 52.8 ± 11.9, 36.9 ± 10.3 g), Venda (45.9 ± 18.4 g, 35.4 ± 10.3 g) and Seshego (42.9 ± 12.2 g, 34.4 ± 8.5 g) for males and females respectively raised in dome ponds. A similar pattern of males growing quicker than females was also observed during the nursery phase.

Overall performance, based on the fry production, nursery and grow-out phases, proved the Zulu and Venda strains to be the best candidates, followed by the Seshego and Red strains.

The following aquaculture reproductive characteristics need further investigation: 1 Number of days until first fry are observed, 2 degree-days needed to produce smaller than 14 mm swim-up fry, and 3 the total number of fry that can be produced per strain. The difference between male and female observed during nursery phase need further investigation, as this was not expected. Further experimentation at farm level is recommended before final conclusions are made, under commercial and small-scale conditions. This should include mortality data and high stocking densities.

CHAPTER 1

BACKGROUND AND OVERVIEW

Table of contents page

CHAPTER 1

BACKGROUND AND OVERVIEW

1.1. INTRODUCTION

Although aquaculture is closely related to agriculture and has been practiced for thousands of years, it is a relatively new discipline as an academic field. In promoting aquaculture development, much can be learned from experiences in agriculture. Unfortunately, until now the majority of South African universities and Non-Governmental Organisations have devoted little attention to aquaculture, which is generally considered to be a branch of capture fisheries.

Fish farming, particularly tilapia, though being relatively young in South Africa, integrates very well with other agricultural activities and suites both small-scale and commercial farmers (Cook, 1995 and Murray *et al.*, 2001). Fish farming contributes to the economy through community welfare and development projects, by creating job opportunities and the alleviation of malnutrition since fish can be a source of alternative animal protein.

The scientific findings and outcomes of this research project will be of value locally and internationally. It will also be of value as a base line for on-going research at the Aquaculture Research Unit (ARU), which is aimed at selecting and improving indigenous strains of the Mozambique tilapia, *Oreochromis mossambicus*, for aquaculture. This will be done by integrating research in various fields e.g. nutrition, genetics, reproduction and growth (Meyer, 2000).

1.2. LITERATURE REVIEW

Tilapiines are naturally distributed in tropical Africa and the Levant (near-Middle East) (Skelton, 1993), but interest in their aquacultural potential has led to nearly worldwide distribution within the past fifty years (Hanley, 1991; Watanabe, 1991; Popma and Lovshin, 1996 and Hena *et al.*, 2005). World wide freshwater tilapia production was 1 254 922 and 1 424 177 metric tons in 2002 and 2003 respectively (http://www.fao.org) and it exceeds 850 000 tons annually in a range of

countries e.g. Thailand, Taiwan, China, Philippines and the USA (Coward and Bromage, 2000).

There is a tremendous increase in demand for tilapia either processed or fresh. The high demand is from developed countries where conditions are not suitable for year round production of tilapia (Popma and Lovshin, 1996). The world-wide culture of tilapiines is increasing because they grow fast, are easy to feed, tolerate poor water quality, are resistant to disease, reproduce with ease, are easily cultured and produce high yields under optimal conditions (Kuwaye *et al.*, 1993; Brad and Phelps, 1995; Phelps *et al.*, 1995; Rowena *et al.*, 1999 and Rutten *et al.*, 2004).

Table 1.1 gives an indication of South African aquaculture production of tilapia in metric tons. There has been a steady increase in tilapia production (in 1988, 20 metric tons were produced) from the late 1980`s until middle 1990`s (in 1994, 60 metric tons were produced), followed by drastic decreases in 1995 where 25 metric tons were produced. However, the production seems to be increasing, since 5 metric tons more have been produced in 1997 (Hoffman *et al.*, 2000). The gate value of tilapia production was R780 000 in 1993/94 according to Holmens (1996) and R200 000 in 1997 according to Hoffman *et al.* (2000).

Table 1.1. South African freshwater aquaculture production of tilapia, 1988 to 1997 (adapted from Holmens, 1996 and Hoffman *et al.*, 2000)

Year	Production in metric tons	
	Holmens (1996)	Hoffman *et al.* (2000)
1988	20	-
1989	20	-
1990	30	-
1991	40	-
1992	55	-
1993	80	60
1994	-	60
1995	-	25
1996	-	15
1997	-	20

Despite the increase in demand for tilapia and its potential as an aquaculture species, there are a number of factors inhibiting tilapia production. The world culture of tilapia species is hindered by early sexual maturity and frequent spawnings that result in overpopulation of production ponds and stunted growth, especially in the case of *Oreochromis mossambicus* (Brad and Phelps, 1995 and Biswas *et al.*, 2005). As a consequence, one of the major challenges facing researchers, as far as the suitability of tilapia species for aquaculture is concerned, is to develop mechanisms to control excessive reproduction and to select the strains with a faster growth rate.

The major challenge facing the tilapia farmers in South Africa is the availability of suitable indigenous strains of *O. mossambicus* for aquaculture. The local farmers are not allowed to farm with *Oreochromis niloticus* since it is an exotic species even though it is known to grow faster under similar conditions than *O. mossambicus* (Moralee and Van der Waal, 2000 and Van der Waal and Bills, 2000).

Extensive research has been done on *O. niloticus* (Popma and Green, 1990; Green and Teichert-Coddington, 1992; Phelps and Cerezo, 1992; Green and Teichert-Coddington, 1994; Phelps *at al.*, 1995; Guerrero and Guerrero, 1999 and Little and Peter, 2004), increasing the suitability and yield of *O. niloticus* for aquaculture. Most of the research that has been done on *O. mossambicus* is based on small populations in European and Far Eastern countries and less in Africa where it originates. These circumstances limit *O. mossambicus* from reaching its full potential as an aquacultural species.

The culturing of *O. mossambicus* as an aquacultural species in South Africa is advantageous since it is found naturally in most rivers (Caulton, 1979) and hence would not out-compete other fish species in the natural water bodies (Moralee and Van der Waal, 2000). The selection and improvement of local strains of tilapia will benefit aquaculture production of local farmers. The developments in the culture of tilapia (genus *Oreochromis*), particularly the Mozambique tilapia (*O. mossambicus*) in South Africa include: research on a seasonal rotational system, with tilapia as the summer crop and rainbow trout as the winter crop and the identification of strains of tilapia showing significant inter-strain variation and hence having the potential to respond to selection for different economically important traits.

Cook (1995) and Hoffman *et al.* (1995) found that there are potential markets in rural areas for fresh fish. If these potential markets can be optimised by the development of market infrastructure, coupled with the improvement of indigenous fish species and consumer awareness about the nutritional value of fish, it would increase the nutritional status and income of farmers (Mohamed and Dodson, 1998; Zylva, 1999; Murray *et al.*, 2001 and Van Zyl, 2001).

Although certain forms of fish and shellfish farming have been practiced in South Africa for many years, it has only been within about the past decade that aquaculture has shown potential with respect to becoming an economically viable commercial industry (Cook, 1995). There are some constrains to the development of aquaculture in South Africa e.g. low rate of annual rain fall (Smith and Prinsloo, 1993). There is considerable opportunity for expansion of the aquaculture industry (Cook, 1995). What is now needed in South Africa is a coordinated aquaculture development plan with governmental funding for research and development (Smith and Prinsloo, 1993 and Cook, 1995).

1.3. OBJECTIVE

The main objective of this research project is to assess the genetic suitability of the four strains of the indigenous Mozambique tilapia, *O. mossambicus* (Peters) that were collected in South Africa. Three phases of the production cycle will be included in the study, namely: fry production phase, nursery phase and grow-out phase. Comparisons of growth during the nursery phase and the grow-out phase will be used as biological parameters to assess the genetic suitability of these four strains of tilapia for different aquaculture production systems.

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CHAPTER 2

FRY PRODUCTION

Table of contents page

CHAPTER 2

FRY PRODUCTION

2.1. INTRODUCTION

The fry production phase is an essential factor in an aquacultural venture. Hatcheries are either privately owned by the farmers or belong to the government (Hulata, 1997 and Moralee and Van der Waal, 2000). Farmers that have their own hatchery do so as a protective measure against diseases that may be introduced into the farm. In such hatcheries there is usually inbreeding and no proper record of broodstock. A proper breeding programme and hatchery management skills are necessary to avoid inbreeding and the consequences thereof. Vrijenhoek (1998) and Henryon *et al.* (1999) indicated that genetic parameters must also be considered when designing breeding programmes in captivity in order to avoid inbreeding depression and artificial selection that may impact on Darwinian fitness. A good hatchery environment allows the full expression of a stock's potential (Bolivar *et al.*, 1993; Tave, 1993; Vrijenhoek, 1998; Coward and Bromage, 2000 and Brown and Laland, 2001).

The aim of this phase was to produce enough fingerlings for the grow-out phase and to acquire basic knowledge of the aquacultural characteristics of each strain for future research during fry production.

2.2. LITERATURE REVIEW

One of the conditions that determine the suitability of species for aquaculture, amongst others, is the ability to reproduce in captivity. *O. mossambicus* is a mouth brooder (Rana, 1988; Skelton, 1993 and Smith and Prinsloo, 1993) that can reproduce in captivity as long as the temperature is above 20°C (Coward *et al.*, 1998 and Oliveira and Almada, 1998).

During the breeding season *O. mossambicus* shows elaborate courtship

(Skelton, 1993 and Feresu-Shonhiwa and Howard, 1998), parental care (Popma and Green, 1990) and aggressive behaviour (Piper *et al.,* 1989; Cornish, 1993; Popma and Lovshin, 1996; Coward *et al.,* 1998; Neat, 1998; McCarthy *et al.,* 1999 and Magurran and Garcia, 2000). The males tend to be aggressive, territorial and excavate a nest on the bottom (Coward *et al.,* 1998; Oliveira and Almada, 1998 and Magurran and Garcia, 2000). The females incubate externally fertilised eggs in their buccal cavities until they hatch (Skelton, 1993 and Hulata, 1997). Phelps and Cerezo (1992), Coward *et al.* (1998) and Neat (1998) found that females also display some aggressive behaviour towards each other during spawning. The high mortality rate during spawning is attributed to aggressive behaviour of brooders (Phelps and Cerezo, 1992 and Nguyen and Little, 2000). Sac-fry remain in the female's mouth through the period of yolk-sac absorption and often seek refuge in her mouth for several days after swim bladder inflation (Hulata *et al.,* 1993; Nicholas and Michael, 1993; Stickney, 1998 and Bhujel, 2000).

Reproduction of tilapia is influenced by exogenous and endogenous factors. These factors act as reproductive stimulii for the onset of breeding. The following factors influence reproduction of tilapia:

- Age and size of female. The younger females are known to spawn more often, with a smaller number of eggs, compared to older females in a breeding season (Jonsson and Jonsson, 1999; Lin *et al.,* 1999 and Little *et al.,* 2003). According to Hulata (1997) high reproductive performance can be achieved from second year female spawners of 150 - 250 g.
- Competition and food supply. Limited food availability that does not allow full appetite satisfaction results in reproduction and growth rates below the maximum potential (Bowen, 1982; Morrison and Wright, 1999; Rahman *et al.,* 2001 and Yang *et al.*, 2003). Tilapia in natural water bodies feed lower down in the food chain, which might be nutritionally insufficient (Zylva, 1999; Huchette *et al.*, 2000; Ujjania *et al.,* 2001; Hakan *et al.,* 2003; Ulloa and Verreth, 2003; Liebert and Portz, 2005 and Shi-Yen and Shu-Lin, 2005).
- pH. Tilapia reproduce and grow better in water that is near neutral or slightly alkaline (Holmens, 1996 and Popma and Lovshin, 1996). Growth has been found to decrease in acidic water due to the low productivity of phytoplankton and zooplankton (Msiska and Costa-Pierce, 1998 and Abdel-Fattah *et al.,* 2003) in

this kind of water. Tilapia can tolerate a pH of 5 and the lethal alkaline limit has been found to be at pH of 10 or above according to Holmens (1996) and Popma and Lovshin (1996).

- Ammonia. Tilapias tolerate un-ionised ammonia concentrations as high as 2.4 mg/ℓ (Popma and Michael, 1999 and Hena *et al.,* 2005).
- Photoperiod. The change in day and night length has an influence on reproduction (Piper *et al.*, 1989; Cornish, 1993; Abdel-Fattah *et al.,* 2004; Camphos-Mendoza *et al.,* 2004; Tarig *et al.,* 2004 and Biswas *et al.,* 2005). The spawning of tilapia has been induced by controlling the light cycle. Response was observed after 8 to 10 hours (Gray, 2003).
- Temperature. This has a major influence on reproduction, more than other factors (Piper *et al.,* 1989; Chmilevskii, 1997; Mélard, 1998; Boeul and Le Bail, 1999; Baras *et al.,* 2000 and Lihsueh *et al.,* 2000).

Tilapia cannot survive water temperatures below 8 - 12°C (Boyd, 1998 and Gregg *et al.,* 1998). Their activity and feeding decline at around 20°C and stop at around 16 °C (Rana, 1988 and Popma and Michael, 1999). The minimum temperature for reproduction is 20°C and the optimum temperature is 30°C (Nicholas and Michael, 1993; Green *et al.,* 1997 and Boyd, 1998). Temperature is, therefore, deemed as one of the critical factors influencing fry production, expressed as degree-days or cumulative degree-days.

According to Popma and Green (1990) and Green and Teichert-Coddington (1992), Reamur proposed the concept of degree-days in 1985, which is mostly used in aquaculture for hatchery management to predict fry production or to induce artificial breeding of broodstock e.g. carp and catfish. Degree-days are calculated as the difference between the mean daily temperature and threshold temperature, which is 15°C, considered to be a practical threshold temperature for reproduction of tilapia. Green and Teichert-Coddington (1992) found that fry production increased significantly with an increase in degree-days.

A 200 degree-day margin has been found to be applicable in predicting when to harvest swim-up fry that are ± 14 mm in length for *O. niloticus*. It has been found that in tilapia the sex of swim-up fry can be phenotypically altered if they are less than 14

mm in length (Popma and Green, 1990; Tave, 1993; Abucay *et al.,* 1999; Baras *et al.,* 2000 and Little and Peter, 2004). This is due to the primordial stage of development before which swim-up fry are neither males nor females (Argue and Phelps, 1995), as they possess neither ovaries, nor testes, or other characteristics associated with the reproductive systems (Tave, 1993). Hence most hatchery managers tend to take advantage of this stage to produce mono-sex fry. Mono-sex culture serves to prevent reproduction during the grow-out phase, thus solving one of the constraints of tilapia production during the grow-out phase, namely, overcrowding and stunting due to early reproduction (Hulata, 1997 and Jana, 1995).

In this research project, it was necessary to have swim-up fry that were of similar size (± 14 mm) in order to start the nursery phase with similar sized swim-up fry and eventually the grow-out phase, since swim-up fry were graded following similar procedures as for sex-reversal (Popma and Green, 1990).

2.3. OBJECTIVE

The objective was to produce enough fry for the grow-out phase; in addition, basic reproductive indicators would be obtained for each strain, which would be useful for further experimentation.

2.4. EXPERIMENTAL PROCEDURE AND MATERIALS

2.4.1. Experimental fish

The research was carried out at the Aquaculture Research Unit (ARU), University of Limpopo, ± 30 km east of Polokwane, the capital city of the Limpopo Province, South Africa. Four strains of Mozambique tilapia were collected at various locations in South Africa. The Zulu and Red strains were obtained from the University of Zululand in KwaZulu-Natal. The Red train is a semi-domesticated strain and was developed in Israel before being transferred to the University of Zululand via the Rand Afrikaans University. The Zulu strain is a wild strain that was collected in KwaZulu-Natal by the University of Zululand. The Seshego strain is also a wild strain collected from the Seshego Dam, an impoundment near Polokwane. The Venda

strain is from the Nwanedi impoundment in the Limpopo river drainage system. All strains were named according to the place of collection, except the Red strain, which was named according to its body colour. The genetic characterisation of the four strains, using alloenzyme (Masetla, 2001) and microsatellite (McCabe, 2001) techniques, indicated that the genetic differences between the Seshego and Venda strain to be small compared to the Red and Zulu strain. This might be due to the fact that they were collected from the same drainage system. However, there were more genetic differences between the Zulu and Red strain.

2.4.2. Breeding facilities

Five 25 m^2, 1 m deep ponds, sealed with a 200 µm plastic lining, were used for the production of fry. The breeding ponds were housed in a plastic covered greenhouse. Each pond was supplied with oxygen from a blower. Asian Institute of Technology type spawning hapas with a 1 mm mesh opening were suspended in each pond. Spawning hapas were used so that swim-up fry could be harvested with ease and low mortality (Popma and Green, 1990 and Argue and Phelps, 1995).

2.4.3. Water quality and growth parameters

Daily temperature (°C) was measured using the hydrothermograph. pH was measured using a Hanna pH meter model HI 8424. The accuracies attained were pH ± 0.01 and temperature ± 0.4 °C. Fish was weighed using a Mettler Toledo PB 8001 electronic balance, with an accuracy of ± 0.1 g, and a 30 cm ruler was used to measure total length in mm.

2.4.4. Broodstock selection

Broodstock were randomly selected before spawning, with average mass and length as indicated in Table 2.1. The large standard deviation in mass, especially among female brooders could be attributed to underfeeding. The underfeeding results in underweight, which is indicated by a low standard deviation in length, i.e. fish of the same length with different mass (Busacker *et al.*, 1990; Martin-Smith, 1996 and Hockaday *et al.*, 2000).

Table 2.1. Mass and length of broodstock selected for breeding of four strains of *O. mossambicus*

Strain	Sex			
	Females		Males	
	Mass (g) Mean ± SD	Length (mm) Mean ± SD	Mass (g) Mean ± SD	Length (mm) Mean ± SD
Red 1	104.6 ± 8.7	177.3 ± 9.6	106.4 ± 7.7	203.4 ± 8.9
Red 2	104.4 ± 8.9	171.7 ± 8.9	105.4 ± 8.2	202.6 ± 9.4
Seshego	95.9 ± 45.4	190.3 ± 16.6	104.2 ± 10.7	187.4 ± 8.1
Venda	81.4 ± 19.1	171.3 ± 16.6	103.3 ± 10.8	190.0 ± 8.1
Zulu	82.3 ± 39.3	177.9 ± 32.5	83.4 ± 22.6	177.9 ± 18.4

SD = standard deviation

The premaxillary of the upper jaw of all male broodstock was removed using a sharp pair of scissors to minimise injuries to females during spawning (Coward *et al.*, 1998 and Neat, 1998).

2.4.5. Pre-experimental adaptation

Pre-experimental adaptation was done for approximately 15 days prior to breeding. Broodstock were well conditioned by feeding them a balanced 28% protein pelleted diet at a daily rate of 5% of body mass. It was necessary to increase the fertility of the broodstock by increasing the mass of under-fed brooders (Rana, 1988 and Thorpe and Hecht, 1992). Broodstock were separated by both sex and strain so that all broodstock would start breeding at the same time when eventually placed together. The female buccal cavities were checked for the presence of eggs before and after the pre-experimental adaptation period as an assurance that they were not incubating eggs during the adaptation period.

2.4.6. Breeding

The selected broodstock were transferred after the pre-experimental adaptation period and paired for spawning in the breeding tunnel (Appendix 2.1). The total number of broodstock that were used during the breeding programme is shown in Table 2.2, at a stocking density of approximately 1 fish per 33 ℓ of water.

The Red strain was replicated twice in order to have more swim-up fry (i.e. Red 1 and Red 2, Table 2.2). The broodstock were mated with a ratio of 2:1 (female:male ratio) (Argue and Phelps, 1995) in order to increase the likelihood of females spawning according to suggestions by Popma and Green (1990) and Jones *et al.* (1998).

Table 2.2. The number of broodstock used for breeding of four strains of O. *mossambicus*

Strain	Sex		Number of ponds used	Total number of brood-stock per strain
	Females	Males		
Red 1	50	25	1	75
Red 2	50	25	1	75
Seshego	50	25	1	75
Venda	50	25	1	75
Zulu	50	25	1	75

Broodstock were fed a pelleted feed with a 28% protein content at a rate of 1.5% of body mass per day during spawning (Popma and Green, 1990 and Argue and Phelps, 1995). The ration was divided into two portions per day. This was done to increase feed utilisation and to avoid waste that might result in poor water quality (Thorpe and Hecht, 1992).

During the breeding period, the physical water quality parameters (temperature and pH) in the fish ponds were tested twice per day, i.e. in the morning (08h00 - 09h00) and in the afternoon (16h00 - 17h00). The recorded temperature was used for the calculation of degree-days according to Green and Teichert-Coddington (1992).

2.4.7. Fry harvest

Swim-up fry of all four strains were harvested when the majority where within the range of 3 - 14 mm. This was dependant on the synchronised degree-days hatching period and the subsequent growth of swim-up fry (being affected *inter alia* by fry number). Swim-up fry were collected by crowded into one corner of the hapa by running a pole under the hapa (Jensen, 1990 and Wixson *et al.*, 2000). Swim-up

fry harvested from the breeding ponds were graded with a 3 mm mesh stainless steel grader (Jensen, 1990). Swim-up fry smaller than 14 mm in length were counted separately from those bigger than 14 mm. This was done in order to obtain swim-up fry with a length of less than 14 mm for all four strains (Panagiotaki and Geffen, 1992 and Basiao *et al.*, 1996) in order to have fry of similar size for the nursery and grow-out phase.

2.4.8. Experimental design and data collection

A Completely Randomised Design (CRD) was used when assigning the four strains into five breeding ponds. Replication was done on the Red strain only due to the limited number of breeding ponds and anticipated low breeding capacity of the Red strain as observed during previous experiments.

The number of swim-up fry harvested for each strain was estimated following the procedure suggested by Popma and Green (1990). Swim-up fry were visually counted by placing a standard sample of 100 into a white 2 ℓ ice cream container as a standard base. Swim-up fry were then added to a similar container with an equal amount of water, until the number of swim-up fry in each container appeared to be the same (Popma and Green, 1990). The total number of swim-up fry was then calculated.

2.4.9. Statistical analysis

One-way analysis of variance was used to test significant differences between breeding ponds using the STATISTIX analytical software programme (1998 update). The number of swim-up fry produced was used as preliminary results for possible future research.

2.5. RESULTS

2.5.1. Water quality

2.5.1.1. pH: The pH dropped down to 4.90 in the morning and increased to 9.83 in the afternoon. The remainder of the pH values obtained during the breeding phase are as indicated in Table 2.3.

2.5.1.2. Temperature: The morning and afternoon daily mean water temperatures were as indicated in Table 2.3. The water of the ponds in the center of the breeding tunnel was warmer (i.e. specifically for the Red and Seshego strains) than those on the outside (i.e. the Venda and Zulu strains).

Table 2.3. Daily pond water temperature (°C) and pH range observed when breeding four strains of *O. mossambicus*

	Morning			Afternoon		
	Temperature (°C)	pH range		Temperature (°C)	pH range	
Strains	Mean ± SD	Min.	Max.	Mean ± SD	Min.	Max.
Red	30.2 ± 1.6	4.92	6.29	33.8 ± 1.7	5.11	8.96
Seshego	30.2 ± 1.4	4.92	6.32	33.8 ± 1.5	5.09	9.27
Venda	29.0 ± 1.5	4.92	6.34	33.0 ± 1.7	5.08	9.83
Zulu	28.9 ± 1.7	4.90	6.27	32.4 ± 1.6	5.09	8.56

SD = Standard deviation

One-way analysis of variance of the daily pond water temperature showed a significant difference between the four breeding ponds ($p \leq 0.05$, Appendix 2.2). Least Significant Difference (LSD) emphasised that there were two groups in which the means were not significantly different from one another.

2.5.2. Degree-days and breeding period

A discrepancy was observed in the degree-days calculated when swim-up fry were first observed. The cumulative degree-days for the first swim-up fry to be observed were 199.8 (Seshego strain), 188.3 (Venda strain), 183.7 (Zulu strain) and 180.3 (Red strain). This discrepancy can be partially explained by the fact that observations were conducted once per day, creating relatively large increases in

degree-days between observations. The swim-up fry were harvested on day 17 at calculated degree-days of 289.4, 288.8, 270.0 and 266.4 for the Red, Seshego, Venda and Zulu strains respectively.

2.5.3. Number of swim-up fry

The number of estimated swim-up fry obtained is shown in Table 2.4. The Zulu strain (8 825) had the highest total number of estimated swim-up fry, followed by the Venda (7 500), Seshego (5 625) and Red strains (3 300). Note that the sac-fry and eggs collected from the mouth of female broodstock during final harvesting were not included in the estimated total number of swim-up fry.

Table 2.4. The total number of estimated swim-up fry harvested when mass breeding four strains of *O. mossambicus*

Strain	Less than 14 mm			Greater than 14 mm		Total number
	Number	Length (mm) Average ± SD	Mass (g) of 100 fry	Number	Mass (g) of 100 fry	
Zulu	5 000	9.5 ± 2.5	15.4	3 825	24.0	8 825
Venda	3 000	10.1 ± 2.3	17.8	4 500	35.6	7 500
Seshego	1 800	8.6 ± 2.2	27.6	3 825	41.0	5 625
Red 1	1 100	9.7 ± 2.1	31.3	600	32.1	1 700
Red 2	400	9.9 ± 2.3	31.7	1 200	32.7	1 600
Red total	1 500	9.8 ± 2.2	31.5	1 800	32.4	3 300

SD = Standard deviation

2.6. DISCUSSION AND CONCLUSIONS

The number of swim-up fry obtained were not analysed statistically since only basic aquacultural characteristics or indicators for each strain were obtained and no replications were done.

2.6.1. *Water quality*

2.6.1.1. pH: The morning and afternoon pH range remained below the ideal value that is suitable and acceptable for the reproduction of *O. mossambicus* which is 7.8 – 8.5 (Gray, 2003). This might have negatively influenced the number of fry produced. However, Popma and Michael (1999) and Abdel-Fattah *et al.* (2005) found tilapia to reproduce at the pH value of 5 to 9.5. Furthermore, Beem (1998) suggested 4 – 10 and 6.5 – 9 as the range and optimum value for red tilapia.

2.6.1.2. Temperature: The significant difference in temperature between breeding ponds influenced the number of swim-up fry produced since ponds with a warmer water temperature had a lower number of swim-up fry. The higher temperature had a negative influence on reproduction since the optimum range for *O. mossambicus* is 23 – 28 °C (Gray, 2003). It has been found that tilapia reproduction increases with temperature until 28 °C.

2.6.2. Degree-days and breeding period

The first swim-up fry were generally observed within the range of 180 to 200 cumulative degree-days for all four strains. One would expect that swim-up fry will first be observed around 180 degree-days for all four strains after stocking of broodstock. The difference in the day swim-up fry were first observed might be due to the observed discrepancy in degree-days and not necessarily reflecting differences between strains. This needs to be investigated more especially if the swim-up fry are to be hormonally sex reversed using hormones. This might also be a reflection of adaptability, with those strains that have a long history in captivity willing to release their swim-up fry from the month sooner than the ones that have a shorter history in captivity.

In order to harvest swim-up fry that are smaller than 14 mm in length, 200 degree-days is generally accepted for *O. niloticus* (Popma and Green, 1990). There are no degree-days margins that have been set for *O. mossambicus,* hence *O. niloticus* values were used as standard for this experiment. The swim-up fry were harvested at calculated degree-days of 289.4, 288.8, 270.0 and 266.4 for the Red, Seshego, Venda and Zulu strains respectively.

The positioning of the ponds in the breeding tunnel influenced the degree-days at harvest. The ponds stocked with the Red and Seshego strains were in the center of a plastic covered greenhouse, as indicated in Appendix 2.1, and hence somewhat warmer (Table 2.3). This was reflected by the fact that they accumulated the highest number of degree-days at harvest of 289.4 and 288.8. The ponds stocked with the Zulu and Venda strain were on the side next to the doors of the plastic covered greenhouse and hence cooler than the middle ones. This was shown by the lower number of cumulative degree-days at harvest of 266.4 and 270.0 for the Zulu and Venda strains respectively. This was also reflected when comparing daily mean water temperature using LSD (Appendix 2.2). Further experimentation is needed to verify degree-days for harvesting swim-up fry of less than 14 mm for *O. mossambicus*, since the swim-up fry were harvested at different degree-days. Furthermore, most of the swim-up harvested were greater than 14 mm. This is more critical when "hormonal sex reversal" is an option for the production of all male fingerlings.

The number of breeding days spent till harvest (17 days) were two days less compared to the results of Argue and Phelps (1995), who required 19 days to produce swim-up fry that were smaller than 14 mm for sex reversal. The difference in the number of days required may indicate that fewer days are needed to produce 14 mm swim-up fry in the case of *O. mossambicus* compared to *O. niloticus*. This might be more critical for the Red strain since 60% of the total fry produced were larger than 14 mm. Nicholas and Michael (1993) found that the difference in the number of days after which swim-up fry were observed was a reflection of the environmental condition where the strain was collected.

2.6.3. Number of fry produced

The total estimated number of swim-up fry produced by each strain, i.e. 3 300 for Red, 5 625 for Sheshego, 7 500 for Venda and 8 825 for Zulu strain, was within the expected range, except for the Red strain (Table 2.4), according to the figures published by Popma and Green (1990). Broodstock with a total biomass ranging from 70 to 100 kg can produce up to 50 000 swim-up fry per cycle. The Zulu and Venda strains produced the highest number of fry during the experimental period. The larger size of fry at harvest is an additional advantage for both the Venda and Zulu strains. The lower mass at harvest is due to the larger number of fry that consequently affected the food availability to the individual fry. The following percentage of estimated total number of swim-up fry smaller than 14 mm were obtained: Zulu 56.6%, Venda 40.0%, Seshego 32.0% and Red 45.5%. This indicates that specific degree-day margins, suitable for *O. mossambicus*, must be set.

Although two replications of the Red strain were used, a smaller number of swim-up fry were obtained for both sizes (i.e. smaller and larger than 14 mm). This confirms several findings that red tilapia strains generally have a low reproductive performance compared to normal strains (Hulata *et al.*, 1995). According to Hulata *et al.* (1995), Popma and Lovshin (1996) and Karayucel *et al.* (2004) the poor performance of red strains is linked to the red colour that is being selected for, and is also negatively affecting egg hatchability, fry survival rate and low growth during the nursery and grow-out phase. The reproductive genetic difference between the other three strains might have influenced the number of swim-up fry produced.

Efficient reproduction is of special importance and low egg production and lack of spawning synchrony are some of the major problems of mass seed production in mouthbrooding tilapia as observed by Bhujel (2000); Coward and Bromage (2000) and Shelton (2000). Further investigation needs to be done (possibly in selection, cross-breeding or other strategies) to overcome these constrains.

2.6.4. Conclusion

The observations from the fry production phase supplied some base-line data; it also showed that further experimentation is necessary before any final conclusions can be made. The following aquacultural reproductive characteristics need further investigation:

- Number of days until first fry are observed
- Degree-days needed to produce smaller than 14 mm swim-up fry, and
- The total number of fry that can be produced per strain.

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CHAPTER 3

NURSERY PHASE

Table of contents — page

CHAPTER 3

NURSERY PHASE

3.1. INTRODUCTION

The identification of relatively fast growing strains early in their life cycle is important in genetic selection programs and in aquaculture management (Palada-de Vera and Eknath, 1993 and Marengoni and Onoue, 1998). For selection and size-grading to be effective, it is imperative to understand the growth characteristics of individuals or groups of individuals under communal stocking in targeted fish farming environments. Most importantly, the relative growth rates of individuals during various stages of the production cycle should be predictable with a high degree of accuracy (Palada-de Vera and Eknath, 1993; Hockaday *et al.,* 2000 and Rutten *et al.,* 2004).

This investigation aimed at comparing and ranking four indigenous strains of Mozambique tilapia in terms of growth performance during the nursery phase. The following biological measurements were used for the comparison of the strains: survival rate, mean increase in length and final weight at harvest.

3.2. LITERATURE REVIEW

The nursery phase entails the rearing of swim-up fry to a size that is suitable for grow-out (Rakocy and McGinty, 1989 and Becker *et al.,* 1999). The time frame of the nursery phase differs from hatchery to hatchery and from species to species. The nursery phase follows after fry have been harvested from the breeding ponds/tanks of the hatchery (Phelps *et al.,* 1995 and Hulata, 1997). In the case of seed that has been harvested from the wild it starts from stocking in the nursery production facility (Nguyen and Little, 2000 and Brown and Laland, 2001). The success of the nursery phase depends on various factors e.g. survival rate, temperature, feed, oxygen concentration, ammonia concentration, etc.

The necessity of pre-determining the growth performance of farmed animals plays a major role in terms of profitability (Bolivar, 1994; Hockaday *et al.,* 2000 and

Yang *et al.*, 2003). On the other hand before any predictions can be made, environmental factors must not be overlooked. Among others the following factors are considered to be major factors influencing the growth and outcome of the nursery phase:

- *Genetic material:* A crucial question for aquaculture geneticists is whether the growth of fish or the traits of interest have a sufficiently high heritability to be worth selecting for (Purdom, 1993; Tave, 1993; Feresu-Shonhiwa and Howard, 1998; Gregg *et al.,* 1998 and Rahman *et al.,* 2001). Vrijenhoek (1998), Henryon *et al.* (1999), Jenneckens *et al.* (1999) and Coward and Bromage (2000) indicated that when designing breeding programmes in captivity, genetics must be considered in order to avoid inbreeding depression and artificial selection that may impact on Darwinian fitness. The heritability of growth from the F_1 generation to the F_2 generation of *O. niloticus* was found to be less than 10% by Rahman and Maclean (1999).
- *Temperature:* Fish are poikilothermic; hence temperature plays a major role in their metabolic activity. The preferred temperature range for optimum growth of tilapia is 24 to 32 °C (Racocy and McGinty, 1989; Soderberg, 1997; Teichert-Coddington *et al.*, 1997; Desprez and Melard, 1998 and Weyl and Hecht, 1998). Growth has been found to diminish significantly below 20°C and mortality can occur below 11°C. At temperature below 11°C, tilapia loses its resistance to diseases and are subjected to infection by bacteria, fungi and parasites (Chmilevskii, 1996 and Chmilevskii 1999). Abucay *et al.* (1999), Baras *et al.* (2000) and Lihsueh *et al.* (2000) indicated that temperature has a significant influence on the male to female sex ratio of *Oreochromis aureus* and *Oreochromis mossambicus* during the first 28 days of exogenous feeding. According to Boeul and Le Bail (1999), Lovshin (undated) and Campos-Mendoza *et al.* (2004), fish species need a minimal threshold of light intensity to be able to develop and grow normally.
- *Dissolved oxygen:* According to Lovshin (undated), the maximum biomass of fish that can be produced in a unit of water depends on the quality and quantity of the ration that can be put into the pond without causing dissolved oxygen concentrations in the culture unit to drop to levels that are stressful or fatal to the fish. Low dissolved oxygen is considered to be the first water quality constraint in

a culture system (Popma and Lovshin, 1996 and Racocy, 1989). Tilapia can survive in 2 or 3 mg/ℓ of dissolved oxygen; however for good growth dissolved oxygen must be maintained at 5 mg/ℓ (Popma and Lovshin, 1996 and Racocy, 1989).

- *Ammonia:* Fish excrete most of their nitrogenous waste in the form of ammonia, which can accumulate in culture units to a level of as high as 1 to 2 mg/ℓ. In water ammonia occurs in two forms, ammonia (NH_3 or un-ionised ammonia) and ammonium (NH_4^+ or ionized ammonia). The form that is toxic to fish is ammonia (NH_3) and is favoured by high temperature and pH. The toxic level of ammonia for tilapia is between 0.6 – 2.0 mg/ℓ and they could begin to die above this level. Suresh (1999) found that prolonged exposure to sub-lethal concentrations of ammonia (1.1 - 3.3 mg/ℓ) can reduce the ability of tilapia to transport oxygen in the arterial blood and unload carbon dioxide from the venous blood.
- *pH:* Tilapia grows better in water that is near neutral or slightly alkaline. Growth has been found to decrease in acidic water due to the low productivity of the water. Tilapia can tolerate a pH of 5 and the lethal alkaline limit has been found to be a pH of 10 or above (Holmens, 1996; Popma and Lovshin, 1996; Nolan *et al.,* 1999 and Hena *et al.,* 2005).
- *Nutrition:* Juvenile fish require a complete and balanced nutritional diet for optimum growth. A high protein diet is recommended for fry during the nursery phase for optimum growth (Popma and Green, 1990; McCarthy *et al.*, 1999 and Morrison and Wright, 1999). The protein content that is suitable during the nursery phase ranges from 25 to as high as 40% protein (Ell-Dahhar and Lovell, 1995). Tilapia are known to utilise phytoplankton as a source of protein when reared under natural pond conditions (Rowena *et al.,* 1999; Zylva, 1999; Huchette *et al.,* 2000; Ujjania *et al.,* 2001; Hakan *et al.,* 2003; Ulloa and Verreth, 2003 and Shi-Yen and Shu-Lin, 2005).
- *Stocking density:* In fish populations, social interaction is known to affect individual growth rate, resulting in size-frequency distributions with a large variation. Basiao *et al.* (1996) suggested that competition for a limited food supply could give rise to a lowered growth rate; however, low growth rate occurs even when food is not a limiting factor (Suresh and Kwei Lin, 1992; Moralee and Van der Waal, 2000 and Little *et al.,* 2003). High stocking density has the potential of

reducing confounding environmental effects associated with fish behaviour (Graham and Bakar, 1999). Tilapia are known to be territorial and this trait can be eliminated by increased stocking densities. The following densities have been suggested during the nursery phase: 8 000 fry/ha to produce 100 g fish after eighteen weeks, 16 000 fry/ha to produce 50 g fish after twelve weeks and 28 800 fry/ha to produce 27 g fish after nine weeks according to Rakocy and McGinty (1989).

3.3. OBJECTIVE

The objective of the study was to compare growth during the nursery phase of the four strains of *O. mossambicus*. The weight at harvest was statistically analysed for the growth comparison of the four different strains.

3.4. EXPERIMENTAL PROCEDURE AND MATERIALS

3.4.1. Experimental fish

Swim-up fry of the four strains of Mozambique tilapia were used. The detailed description of the origin of the four strains appears in Chapter 2.

3.4.2. Nursery phase facilities

Nine 1 200 ℓ fiberglass tanks were used for the nursery phase. The tanks where housed inside a polycarbonate plastic greenhouse equipped with two automatic fans and two blowers. Water from all tanks was filtered through the same brush filter system (Appendix 3.4. Figure A and B). Eleven 700 ℓ glass aquaria were also used. Each aquarium has a separate 125 ℓ gravel glass aquarium filter system (Appendix 3.4. Figure C). All tanks and aquaria were supplied with compressed air from a blower.

3.4.3. Water quality and growth parameters

pH and temperature were measured using a Hanna pH meter model HI 8424. The accuracies attained were pH ± 0.01 and temperature ± 0.4 °C. Mass was weighed using a Mettler Toledo PB 8001 electronic balance, with accuracy of ± 0.1 g and a 30 cm ruler was used to measure total length in mm.

3.4.4. Nursery phase division

The experimental swim-up fry were harvested after spawning as described in the fry production phase in Chapter 2. The nursery phase was divided into primary and secondary nursery phases according to the water exchange and type of feed used.

3.4.4.1. Primary nursery phase: The primary nursery phase was characterised by a water exchange of approximately 50% every third day, i.e. 600 ℓ, with an isolated closed tank recirculation system consisting of an airlift pump and a gravel filter in each tank (Appendix 3.1. Figure A). An isolated closed tank recirculation system was used so that swim-up fry would not escape from the tanks. The four strains were distributed randomly in fibreglass tanks and glass aquaria. In case of the glass aquaria 50% of water was exchanged every third day i.e. 350 ℓ.

Trout starter powder feeds grade 00 and 01 were used. The two trout starter powder feeds contain 40% protein. The high protein diet was used to increase growth (Ell-Dahhar and Lovell, 1995). Grade 00 is characterised by small particles of feed as compared to grade 01. The two grades were gradually changed depending on the size of the fry. The primary nursery phase was changed to a secondary phase after 3 weeks.

3.4.4.2. Secondary nursery phase: The secondary nursery phase was characterised by a system operated as an open recirculating system in tanks (Appendix 3.1. Figure B). Fry were fed small pellets (4 mm) with a protein content of 28% (ARU standard diet) until harvest. The open recirculation system was used in order to improve water quality by flushing all waste products. Water outlets were fitted with a screen sieve to avoid fry from escaping. The secondary nursery phase was terminated after 12 weeks. During the secondary nursery phase In case of the glass aquaria ARU

standard diet were used until harvest with 50% water exchange every third day.

3.4.5. Stocking density

The standard lengths (mm) of 100 swim-up fry were measured and the bulked biomass of 100 swim-up fry was weighed at stocking. The swim-up fry reared in 1 400 ℓ tanks were stocked at the following stocking densities: 0.89, 0.67, 0.84, and 0.89 fry/ℓ for the Red, Seshego, Venda and Zulu strain respectively, as indicated in Table 3.1. The difference in stocking density was due to a lower number of appropriate size swim-up fry produced during mass breeding (Chapter 2). The swim-up fry in 700 ℓ glass aquaria were stocked at a density of 3 fry/ℓ for the four tilapia strains.

3.4.6. Feeding

Swim-up fry were initially fed trout starter feed at rates suggested by De Silva and Anderson (1995), this was followed by the ARU standard diet for tilapia. The initial feeding was at a rate of 30% of body mass per day for fish ranging from 0.5 to 5 g and gradually decreased to 20% of body mass per day for fish ranging from 5 to 10 g. Feed was adjusted according to the anticipated growth rate in relation to the water temperature, as indicated by Popma and Green (1990). The total mass of feed to be fed per day was divided into three equal portions to increase feed utilisation and reduce water contamination (Thorpe and Hecht, 1992).

3.4.7. Experimental design and data collection

A Completely Randomised Design was used when assigning the fry of the four strains to the fiberglass tanks and glass aquaria during the nursery phase.

The standard length of a sample of 100 swim up fry was measured at stocking for all four strains. The mass was estimated based on the length-weight relationship for feeding as suggested by Popma and Green (1990). To minimise mortality since juvenile fish are more susceptible to stress from handling and tend to be more susceptible to diseases (Hulata, 1997), the standard length was taken only at stocking and at harvest. The high mortality rates experienced during the first sampling led to the reduction in the number of samplings, which was originally

scheduled for once every week, since high mortality would limit the number of fingerlings available for the grow-out phase. Furthermore, frequent sampling reduces growth by 25 to 50%, as observed by Bolivar (1994). The sampling was done at stocking and at harvest by weighing and measuring fish individually and separated by strain and sex for comparison. Fry were harvested after 15 weeks and fish weighed individually.

Water temperature (°C) and pH was taken twice per day, in the morning (08h00 - 09h000) and in the afternoon (16h00 - 17h00).

3.4.8. Statistical analysis

The weight at harvest and differences between males and females across strains at harvest were used to compare strains. The one way analysis of variance was used to test for significant differences between mean weight at harvest using the STATISTIX analytical software programme (SXW (1998)).

3.5. RESULTS

3.5.1. Stocking density and average length

Table 3.1 indicates the number of tanks or aquaria, stocking density per tank/aquaria, initial mass (g) and length (mm) at stocking of the four strains of *O. mossambicus*.

Table 3.1. Number of tanks and aquaria, stocking density, mean length, estimated initial mass and total biomass at stocking of four strains of *O. mossambicus*

Nursery rearing unit Tanks					
Strains	**No of tanks**	**Stocking density**	**Length (mm) Mean ± SD**	**Estimated initial mass (g)**	**Biomass (g)/tank**
Red	1	1 200	9.81 ± 2.18	0.32	384
Seshego	2	900	8.64 ± 2.13	0.27	243
Venda	3	1 133	10.10 ± 2.27	0.18	204
Zulu	3	1 200	9.53 ± 2.45	0.15	180
Nursery rearing unit Aquaria					
Strains	**No of aquaria**	**Stocking density**	**Length (mm) Mean ± SD**	**Estimated initial mass (g)**	**Biomass (g)/aquarium**
Red	1	900	9.81 ± 2.18	0.32	288
Seshego	3	900	8.64 ± 2.13	0.27	243
Venda	3	900	10.10 ± 2.27	0.18	162
Zulu	4	900	9.53 ± 2.45	0.15	135

SD = Standard deviation

The one-way analysis of variance (ANOVA) indicated that the difference in mean length between the four strains of Mozambique tilapia at stocking was highly significant ($p \leq 0.01$) as indicated in Appendix 3.2. The LSD showed that length at stocking was similar between Venda (10.10 ± 2.27 mm), Red (9.81 ± 2.18 mm) and Zulu (9.53 ± 2.45 mm) and different from Seshego (8.64 ± 2.13 mm), which had the shortest length.

3.5.2. Water quality

3.5.2.1. pH: pH was within the acceptable range of 6.32 - 7.89 in the morning and 7.05 - 9.47 in the afternoon for the swim-up fry that were reared in aquaria (Table 3.2). For the swim-up fry that were reared in tanks the pH was within a similar range of 6.18 - 7.34 in the morning and 7.06 - 8.46 in the afternoon (Table 3.2). The daily pH cycle was such that the morning pH was low and increased in the afternoon in aquaria; similarly in the tanks (Table 3.2). Based on the estimations as used in aquaculture, the other water quality parameters were assumed to be within the acceptable levels which *O. mossambicus* can tolerate during the nursery phase (Soderberg, 1997).

Table 3.2. Morning and afternoon pH range for the two nursery rearing facilities used when raising four strains of *O. mossambicus*

Strain	Fiberglass tanks				Glass aquaria			
	Morning		Afternoon		Morning		Afternoon	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Red	6.42	7.20	7.93	8.44	6.39	7.42	7.15	9.00
Seshego	6.18	7.3	7.92	8.46	6.34	7.45	7.15	9.32
Venda	6.46	7.23	7.91	8.06	6.32	7.69	7.05	9.15
Zulu	6.52	7.34	7.06	8.02	6.36	7.89	7.17	9.47

3.5.2.2. Temperature: The mean daily water temperature was within the range of 26.6 - 28.4 °C for aquaria and tanks (Table 3.3). There were no significant differences between the mean daily water temperatures in tanks (Appendix 3.3.i); a similar scenario was also observed between aquaria (Appendix 3.3.ii).

Table 3.3. The mean daily water temperature in the fiberglass tanks and glass aquaria in which four strains of tilapia were raised during the nursery phase

		Strain			
		Red	Seshego	Venda	Zulu
		Mean ± SD °C	Mean ± SD °C	Mean ± SD °C	Mean ± SD °C
Fiberglass tank no	1	26.8 ± 3.5	27.7 ± 1.1	27.5 ± 1.1	27.4 ± 1.2
	2		26.6 ± 5.0	27.6 ± 1.1	27.2 ± 1.1
	3		26.6 ± 5.0	27.3 ± 1.2	27.5 ± 2.3
Glass aquaria no	1	27.2 ± 2.4	27.2 ± 1.3	27.4 ± 1.5	27.8 ± 1.3
	2		27.7 ± 1.2	27.9 ± 1.5	28.0 ± 1.2
	3		28.4 ± 1.3	28.2 ± 1.6	27.3 ± 1.4
	4				28.2 ± 1.2

SD = Standard deviation

3.5.3. Growth

The growth performance of all four strains was compared on the assumption that they were all exposed to similar environment, since pH and temperature were found to be within a suitable range in a particular nursery facility (Table 3.2, and 3.3; Appendix 3.3.i & 3.3.ii).

3.5.3.1. Strain comparisons: When the four strains were compared the Venda strain (8.9 g) had the highest mass followed by the Zulu (5.3 g) and Seshego (4.3 g)

strains, while the Red strain (3.3 g) had the lowest mass for the fish that were raised in tanks (Appendix 3.4). There were highly significant difference between most of the tanks, and even between the three individual Venda and Zulu tanks. Similarly, for the fish raised in aquaria, the Venda strain (7.2 g) had the highest mass followed by the Zulu (in one individual aquarium, 4.9 g), Seshego (4.8 g) and Red (4.0 g) strains (Appendix 3.5). However, for the fish raised in aquaria the Zulu strain had the lowest mass in two of the aquaria. Again, there were highly significant differences between strains, but no differences between individual Venda and Seshego aquaria.

3.5.3.2. Sex comparison: The general observation when males and females were compared was that the differences between means were statistically highly significant ($p \leq 0.01$), e.g. as indicated for aquaria in Appendix 3.6. However, the Venda females (7.7 g) raised in aquaria had an average mass that was significantly bigger than those of males (Appendix 3.6).

3.6. DISCUSSION AND CONCLUSIONS

3.6.1. Differences at stocking

Differences in length and mass at stocking were also reported by Bolivar *et al.* (1993) when testing the growth and reproduction performance of individually tagged *O. niloticus*, but it did not affect the final growth performance. The difference in size of swim-up fry at stocking is due to the lack of spawning synchrony of the mouthbrooder, *O. mossambicus* (Bhujel, 2000; Little and Peter, 2004 and Biswas *et al.,* 2005). The ovaria do not mature at the same time; consequently, swim-up fry of different masses and lengths were used for the experiment.

3.6.2. *Water quality*

Temperature and pH were mostly at optimum levels that promote growth and do not compromise the immune system (Racocy and McGinty, 1989); that is a pH within the range of 6.18 to 9.47 and temperature within the range of 26 to 29°C, according to Soderberg (1997). Furthermore, there were no apparent significant differences between the rearing facilities as indicated in Table 3.2, 3.3 and Appendix 3.3.

3.6.3. Growth

3.6.3.1. Differences between sexes: The results confirmed the general observation that males grow significantly ($p \leq 0.01$) quicker than females (Appendix 3.6). This general observation was quite surprising at this early developmental stage, since one would expect males to grow faster than females especially during the grow-out phase when they are sexually mature and ready to spawn. This is the time when females use most of their energy for reproduction (production of eggs and brooding, with reduced feeding), whereas males will utilise most of the energy for body tissue. Popma and Michael (1999) indicated that the males grow twice as fast as the females. However, in this study the Venda females had a higher mass than that of males.

3.6.3.2. Differences between strains: If one had to select strains with better juvenile growth rate in the two nursery facilities, the Venda showed a faster growth rate followed by either the Zulu or Seshego strain. There was a re-arrangement in order between the Zulu and Seshego strains between the two facilities. The Red strain seems to have the lowest growth rate.

Generally, the final body weight of the four strains of tilapia at harvest was within the expected range according to the results of Palada-de Vera and Eknath (1993). The weight at harvest was also similar to that found by Bolivar *et al.* (1993) when comparing growth and reproduction of individually tagged Nile tilapia of different strains.

In conclusion, the fact that males grow faster than females already as juvenile tilapia fish appears to be an important factor for the success of any tilapia farm. The faster growth rate of male tilapia fish over females observed at this early stage indicates that all-male tilapia farming may be the better choice (Tuan *et al.*, 1998; Carrasco *et al.*, 1999; Nguyen and Little, 2000 and Little *et al.*, 2003). Further experimentation at farm level is required in order to make final conclusions under commercial conditions as well as in small-scale farming.

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CHAPTER 4

GROW-OUT PHASE

Table of contents

CHAPTER 4

GROW-OUT PHASE

4.1. INTRODUCTION

Tilapiines (family Cichlidae) have been an important source of food for humankind at least since recorded history began; some are popular angling species Le Roux (1961) and many are of great value in aquaculture for commercial and subsistence fisheries (Skelton, 1993).

Evaluation of different tilapia strains for aquaculture purposes has been a subject of many investigations. The importance of choosing appropriate strains for building a base population for selection and improvement cannot be overlooked. According to Rowena *et al.* (1999), Brown and Laland (2001) and Rutten *et al.* (2004) the choice of suitable stocks adapted to culture is important for increasing tilapia production. The necessity of such specific research has been shown in the Philippines by the GIFT project (Bentsen *et al.,* 1998), in Indonesia (Brzeski and Doyle, 1995). Tilapias vary considerably in their growth potential and only those species, which grow to larger and marketable sizes, have been widely cultured (Soderberg, 1997; Ambali *et al.,* 1999; Hockaday *et al.,* 2000 and Huchette and Beveridge, 2003).

The grow-out phase entails the raising of fish to market size. Different fish species vary with respect to the time spent during the grow-out phase. For tilapia species it takes one to two seasons, which can be six to twelve months depending on the temperature and this varies from region to region. In the Philippines tilapia are raised for three months during the grow-out phase (Bolivar *et al.,* 1993); 130 – 190 g wet weight for tilapia is considered to be an acceptable market size in that country (Mair *et al.,* 1995). According to Bolivar *et al.* (1993) and Soderberg (1997), strains with a high average body mass after three months are considered to be suitable for aquaculture, since they have been shown to reach a larger desired body mass during the grow-out phase. Fish growth is frequently projected in time, based on the temperature units required per increment of fish length (Soderberg, 1992; Popma

and Green, 1990 and Baras *et al.*, 2000), commonly expressed in terms of degree-days.

The four indigenous strains of tilapia included in the present study were raised in two different aquacultural production systems with the aim of identifying and selecting suitable strains for farming, since the testing of strains in a growth performance programme should have strong similarities with the targeted farm production systems (Bentsen *et al.*, 1998). This study was aimed at comparing growth performance between the four strains of tilapia and between sexes in two different systems (i.e. recirculating system and semi-intensive system).

4.2. LITERATURE REVIEW

The tilapia possesses a remarkable attribute for aquaculture: excellent growth rate on low protein diets (Eknath, Undated; Bolivar, 1994; Bentsen *et al.*, 1998 and Nolan *et al.*, 1999). Tilapias vary considerably in their growth potential and only those species which grow to larger sizes have been widely cultured (Soderberg, 1997 and Weyl and Hecht, 1998). Although several tilapia species are cultured, the most widely preferred (in over 40 countries) is *O. niloticus* followed by *O. mossambicus* (Hulata *et al.*, 1995; Rahman *et al.*, 2001 and Yang *et al.*, 2003).

The definition of growth from an aquacultural perspective is a complex process by which ingested energy is converted to biomass, restricted by endogenous and exogenous factors (Teichert-Coddington *et al.*, 1997 and Erfanullah and Jafri, 1998). Understanding and controlling these factors is the underlying principle of aquaculture (Soderberg, 1997). Busacker *et al.* (1990) and Hopkins (1992) emphasize that growth is guided or limited by endogenous and exogenous factors. Growth rate of fish in an aquacultural production system depends on many factors, such as:

- *Production system* (Rowena *et al.*, 1999): The growth performance testing programme for different strains requires strong similarities between the tested environment and targeted farm environments (Bentsen *et al.*, 1998). There are different production systems in aquaculture. They differ according to the level of environmental management or modifications, ranging from extensive to intensive

systems (Eknath, Undated; Cook, 1995; Soderberg, 1997 and Hena *et al.,* 2005). The extensive system is were there is no environmental modification e.g. dams or ponds or there is partial modification (Suresh and Lin, 1992). Furthermore, extensive system may involve pond water fertilisation or partial water exchange and feeding (Lovshin, undated and Soderberg, 1997). The intensive system is characterized by complete environmental modification e.g. recirculation systems or raceways (Rani, 1997 and Popma and Micheal, 1999). The intensive system involves complete water exchange, artificial feeding and aeration (Lovshin *et al.,* 1990 and Chmilevskii, 1998). The water quality parameters that are controlled include temperature, dissolved oxygen, ammonia, solid materials, etc (Soderberg, 1997).

- *Species genetic make-up*: The growth potential for any organism is programmed into its genome (Piper *et al.*, 1989; Purdom, 1993; Tave, 1993; Soderberg, 1997; Feresu-Shonhiwa and Howard, 1998; Gregg *et al.*, 1998; Vrijenhoek, 1998 and Rahman and Maclean, 1999). Species and strains that have potential to attain larger maximum body mass are selected for aquaculture in a specific production system (Soderberg, 1997 and Ponzoni *et al.,* 2005). Different species of tilapia are used for aquacultural purposes; *O. niloticus* and *O. mossambicus* are the most cultured species (Hulata *et al.,* 1995 and Jenneckens *et al.,* 1999). *O. niloticus* is known to grow faster than *O. mossambicus (*Moralee and Van der Waal, 2000). Mass selection for growth in tilapias has given different results in different studies; the following growth heritabilities were obtained: 0.10 and 0.16 for males and females of *O. mossambicus*, 0.23 for *Oreochromis aureus* and less than 0.10 for *O. niloticus* (Hulata *et al.,* 1993). According to Graham and Bakar (1999) the estimated heritability for body mass in *O. niloticus* was about 0.25 for all ages from 56 to 126 days. Rutten *et al.* (2005) found heritabilities to be 0.26 for body mass, 0.24 for fillet weight and 0.12 for fillet yield.
- *Stocking density and competition*: Stocking density is defined as the number of fish in a production unit and it is commonly associated with competition (Lovshin *et al.*, 1990; Suresh and Lin, 1992 and Green, 1995). Competition comes into place when there is a low food supply or less space available. In a natural habitat there is a limited number of fish that can be maintained (carrying capacity). Lovshin *et al.* (1990) describe that competition for supplementary feed and

natural pond food between the stocked tilapia and their young reduces growth rate and results in stunted populations. In aquaculture production systems fish are cultured at high stocking densities to utilise each system fully (Soderberg, 1997). Lovshin *et al.* (1990) found that higher stocking rates may result in increased yields without a significant decrease in growth rate. High stocking density has the potential to reduce confounding environmental effects associated with fish behaviour (Graham and Bakar, 1999). The stocking densities can be increased with an increase in environmental modification (Suresh and Lin, 1992). The carrying capacities of production systems are increased by higher management levels e.g. pond fertilisation, artificial feeding, water exchange and aeration. One should also bear in mind that the higher the stocking density, the higher is the risk (Lovshin, undated; Suresh and Lin, 1992 and Little and Peter, 2004).

- *Diet*: In most aquacultural production systems fish depend on artificial feed for optimum growth (Stickney, 1994 and Ell-Dahhar and Lovell, 1995). The feed must have all the ingredients that are necessary for growth. Tilapia is known to require a low dietary protein content (Eknath, Undated; McCarthy *et al.,* 1999; Morrison and Wright, 1999; Zylva, 1999 and Huchette *et al.,* 2000). The stomach content of *Oreochromis mossambicus* was found to contain filamentous algae (5 - 10%), cellular algae (50 – 60%), zooplankton (10 – 15%) and insects (20 – 30%), indicating its ability to utilise various natural food sources (Ujjania *et al.,* 2001; Hakan *et al.*, 2003; Ulloa and Verreth, 2003 and Shi-Yen and Shu-Lin, 2005). The protein requirements are low for growth during the grow-out phase: only 28% protein content, compared to the nursery phase where a minimum of 30% protein content is required (Stickney, 1994; Abucay *et al.,* 1999 and Becker *et al.*, 1999).
- *Sex*: When comparing sexes within a strain; Marengoni and Onoue (1998) found that males grew significantly more rapidly ($p < 0.05$) than females in offspring of a diallel crossbreeding of three strains of *O. niloticus*. The body mass results (mean ± standard deviation) obtained for the three purebred offspring were as follows: Stirling (76.4 ± 7.45 g) and (58.8 ± 6.1 g) for males and females respectively; Korean (66.6 ± 2.8 g) and (45.5 ± 8.2 g) for males and females respectively; and Locals (63.9 ± 6.6 g) and (52.8 ± 6.7 g) for males and females respectively.

Hulata *et al.* (1995) also indicated that males grew significantly faster than females when evaluating some red tilapia strains for aquaculture. Lovshin *et al.* (1990) indicated that males (158 and 150 g) were significantly larger than females (141 and 126 g) for the fish stocked at 5 000 fish/ha and 10 000 fish/ha respectively. The differences between males and females were regardless of the type of production system used. According to the results of Marengoni and Onoue (1998) from the diallel cross of three strains of *O. niloticus* significant differences in growth performance between and within sexes where observed even when reproduction was prevented, i.e. males grew fast than females. The difference in growth performance between males and females is due to the fact that females specifically divert more energy, which could be utilised for somatic growth, into gamete production and behavioural interactions (Mair *et al.*, 1995 and Little *et al.*, 2003).

- *Growth period*: A factor that affects the comparison of growth performance across and within sexes of different strains is time. The time spent during the grow-out phase differs from place to place. Bolivar *et al.* (1993), with tilapia raised in grow-out ponds for three months in the Philippines, did not observe any significant differences between seven strains of *O. niloticus* after 60 days; however, significant differences were observed after 210 days. Palada-De Vera and Eknath (1993) did not detect growth differences between males and females before 129 days and only after 129 days growth differences were observed. For a growth comparison between different strains of tilapia enough time is needed so that significant differences can be displayed and detected. Usually this will differ from place to place depending on the market size required, e.g. according to Mair *et al.* (1995), a 130 – 190 g wet weight of tilapia is acceptable to the market in the Philippines.

The summarised statement that seems to apply for growth comparison across strains was made by Rowena *et al.* (1999) when they expressed that "both strain (genotype) and rearing (environment) influence growth". This statement was made after they had conducted a study on growth of five Asian red tilapia strains in saline environments. Hence, when selecting a strain for culture, one should choose the fastest growing strain for a specific production system.

There are different ways in which growth is reported. An extensive literature review on the different ways in which growth can be expressed in aquaculture was compiled by Soderberg (1992). For the present study, the linear model of growth was chosen, given by the general formula $\Delta L = a + bT$, where ΔL, is the growth rate; a is the intercept on the x/y–axis; b is the slope and T is the temperature in °C. According to this model, the growth rate of fish at constant temperatures (in length units) is linear over time, regardless of fish size (Soderberg, 1992). Soderberg (1997) showed that a linear relationship also applies to tilapia when grown in flowing water on complete diets at densities which preclude spawning behaviour; the equation for *Oreochromis aureus* in that specific situation was $\Delta L = -0.853 + 0.048T$.

Soderberg (1997) and Hockaday *et al.* (2000) indicated that the growth rates of fish were positively correlated with their maximum observed length and suggested that this relationship can be used to evaluate fish species for aquaculture. The change in length or weight of different strains during a specific time span can be compared. The weight gained or the increase in length can be used to compare different strains regardless of the difference in initial weight or length.

4.3. OBJECTIVES

The aim of this investigation was to compare the growth performance of four indigenous tilapia strains growth in three different types of aquacultural production systems. The two production systems finally used are regarded to be suitable for small-scale farmers and commercial farmers in South Africa. For a comparison of growth of the four strains of tilapia, the mean weight was tested statistically for significant differences.

4.4. EXPERIMENTAL PROCEDURE AND MATERIALS

4.4.1. Experimental fish

Four indigenous strains of the Mozambique tilapia, *O. mossambicus*, collected from different geographical areas in South Africa, were used from previous experiment. The different areas of collection were considered to be geographically isolated. The detailed explanation for the origin of the four strains has been given in Chapter 2.

The four strains were differentiated by a dorsal fin spine marking technique according to the method used by Khater (1985). Two of the dorsal fin spines were cut with the aid of a sharp pair of scissors; after healing, a thickened portion on the spine can be identified as indicated in Appendix 4.1. Each strain was identified by its own unique marking code. Fish from the different strains were stocked communally during the grow-out phase, since all four strains were stocked together in each pond/tank to optimise the comparison under the same water conditions.

One of the limitations of the dorsal fin spine marking technique is that it is not easy to report mortality. The dorsal fin spine mark is not clear once the fish is dead, due to damage and fungal infection.

4.4.2. *Grow-out production systems*

Three production systems were initially used to raise fish during the grow-out phase: an extensive integrated system, a semi-intensive static pond system (dome ponds) and an intensive recirculation system. However, the extensive integrated system was terminated due to high mortality of fish, and losses by predatory birds and theft.

4.4.2.1. Static pond system: Six plastic covered dome ponds were used, each with a plastic cover of 7 x 7 m. Each pond of 12.6 m^3 is 0.5 m deep, lined with 200 µm plastic and receives atmospheric air from a blower. Ponds were filled with a gravel layer of about 100 mm thick. Each dome pond was used as a static pond system with a partial water exchange of 30% every second week.

4.4.2.2. Recirculation system: Six 6.4 m^3 high density polyethylene (HDPE) circular tanks, 1 m deep were used. Tanks were housed inside a 27 x 25 m fiberglass greenhouse, fitted with automatic fans. Each tank received atmospheric air supplied by a blower. Each recirculation system consists of five circular tanks connected to a drum filter and biological trickling filter.

4.4.3. *Stocking density and feeding*

The aim was to stock fingerlings at a stocking density of 100 fish per pond in the dome ponds, that is 25 from each strain (Appendix 4.2). The recirculation system was stocked with 400 fish per tank, with 100 from each strain (Appendix 4.2). But due to the limited number of suitable size fingerlings available for the Red and Seshego strains, some tanks were stocked with lower number of fingerlings. Males and females were stocked separately, with three ponds/tanks each. In general, a low stocking density was used so that fish growth would not be limited by the carrying capacity (Lovshin *et al.,* 1990), and that the differences in genetic potential would be fully expressed. Therefore, both aquacultural production systems were not stocked at profitable maximum capacity. Under commercial conditions the strains could thus perform differently.

Fingerlings were fed a pelleted feed, which is the standard tilapia diet manufactured at ARU containing 28% protein. Fish raised in the dome ponds were fed 4% of their body mass daily, with 10% of body mass per day for fish raised in the recirculation system. Fish were fed three times a day by dividing the total daily ration into three portions to improve feed utilisation and minimise water contamination and maintain water quality. Feed was adjusted every four weeks after the fish were weighed.

4.4.4. *Water quality and growth parameters*

The following water quality parameters were measured: oxygen concentration (mg/ℓ) and oxygen percentage saturation using the WTW OXI91 oxygen meter. The accuracies attained were 1% for percentage O_2 saturation and 0.1 mg/ℓ for O_2 concentration. Temperature and pH were measured using the Hanna pH meter model HI 8424. The accuracies attained were pH ± 0.01 and temperature ± 0.4 °C.

Mass was weighed using a Mettler Toledo PB 8001 electronic balance, with accuracy of ± 0.1 g and a 30 cm ruler was used to measure total length in mm.

4.4.5. Experimental design and data collection

Fingerlings were randomly selected for the grow-out phase. The Completely Randomised Design was used when assigning individuals of the four strains of tilapia to rearing units during the grow-out phase.

All fingerlings were counted, sexed and individually weighed and measured at stocking. All fish were again individually weighed and measured in each pond/tank every four weeks during the grow-out phase. After sampling the food ration was adjusted for the four strains of tilapia (Appendix 4.10 and 4. 12), following a similar method as in the GIFT project (Bolivar, 1994).

The water quality parameters were recorded twice per day, in the morning (08h00 – 09h00) and in the afternoon (16h00 – 17h00). Experiments were terminated after 4 months by harvesting all fish, after which all the fish were individually weighed and measured.

4.4.6. Statistical analysis

The mean mass at harvest and differences between males and females across strains at harvest were used to compare the difference between strains. One-way analysis of variance was used to test significant differences between mean mass at harvest using the STATISTIX analytical software programme (1998 update).

4.5. RESULTS

4.5.1. Recirculating system

4.5.1.1. Water quality

As expected water quality parameters within the recirculating system were within a similar range, since water is circulated, heated and filtered through the same filter system. However, the following water quality parameters were monitored during the grow-out phase both in the recirculating system and dome ponds:

4.5.1.1.1. pH: The pH varied between a lowest value of 5.70 in the morning and the highest value of 6.96 in the afternoon (Appendix 4.3). The daily pH cycle was such that it was slightly lower in the morning and somewhat higher in the afternoon. This was not expected since most of the external factors are controlled e.g. temperature and oxygen supply and a constant water exchange, and no algae was present in the system.

4.5.1.1.2. Oxygen concentration (mg/ℓ): The oxygen concentration was within the range of 3.8 mg/ℓ in the morning and 4.0 mg/ℓ in the afternoon (Appendix 4.4). The percentage oxygen saturation was roughly 50% throughout the day.

4.5.1.1.3. Temperature (°C): The mean daily water temperatures were within the range of 21.0 – 23.5 °C for both systems used (Table 4.1). There were no significant differences between the mean daily water temperatures within a system; similarly, when the six tanks used were compared there was no significant difference observed (Appendix 4.5).

Table 4.1. The mean daily water temperature obtained when four strains of tilapia were raised in a recirculating system

Tank	Means ± SD (°C)
S2D1	23.5 ± 10.2
S2D2	23.5 ± 10.3
S2D3	23.4 ± 10.2
S3D1	22.3 ± 9.6
S3D2	21.8 ± 10.0
S3D3	21.0 ± 10.6

SD = Standard deviation

4.5.1.2. Growth comparison

The influence of different stocking densities specifically for the recirculating system was excluded by the fact that fish were fed according to the total biomass in a production unit (Appendix 4.10) and dome pond (Appendix 4.12).

4.5.1.2.1. Sex comparison: i.e. comparison of males and females. Generally, males were significantly bigger than females as indicated in Appendix 4.6, except for the Red strain, where there is no significant difference between males (63.0 g) and females (58.4 g). However, one must appreciate the fact that males are still significantly heavier than female when compared between strains (Appendix 4.6).

4.5.1.2.2. Strain comparison: i.e. regardless of sex. The comparison of means indicated that there is a significant difference between the four strains. The LSD indicated the Zulu and Venda strains to have a similar mean mass of 80.0 and 70.2 g respectively at harvest (Appendix 4.7.). Furthermore, the Venda (70.2 g) and Seshego strain (67.1 g) have similar means with the Red strain (60.6 g) having the lowest mass at harvest (Appendix 4.7).

4.5.2. Dome pond system

4.5.2.1. Water quality

The water quality parameters were slightly different between individual ponds; however; the communal way of stocking reduced the anticipated differences. Similar water quality parameters were measured during the grow-out phase as in the recirculating system:

4.5.2.1.1. pH: The pH was within the range of 6.29 in the morning and 8.49 in the afternoon for the fish raised in dome ponds (Appendix 4.3). The daily cycle of pH was such that the morning pH values were lower with a slightly increase in the afternoon. As compared to the recirculating system this was expected, as the temperature tends to increase during the day until in the afternoon and decreases during the night.

4.5.2.1.2. Oxygen concentration (mg/ℓ): The oxygen concentration for the dome ponds used to raise male fish was within the range of 4.2 mg/ℓ in the morning and

5.5 mg/ℓ in the afternoon (Appendix 4.4). The percentage oxygen saturation was within the range of 52.9 % in the morning and 70.2 % in the afternoon.

4.5.2.1.3. Temperature (°C): Temperature was within the range of 20.7 to 21.2°C, which is within the optimum temperature range for optimum growth of *O. mossambicus*. (Soderberg, 1997). Furthermore, there were no significant differences between the mean water temperatures of the six dome ponds used (Appendix 4.11).

4.5.2.2. Growth comparison

4.5.2.2.1. Sex comparison: i.e. comparison of males and females. As observed in the recirculating system the males were significantly bigger than females as indicated in Appendix 4.8. The Red strain seems to be the exception since the males (33.8 g) were smaller than the females (38.6 g).

4.5.2.2.2. Strain comparison: i.e. regardless of sex. Similarly to what was observed in the recirculating system the Zulu (44.4 g) strain had the highest mean mass at harvest followed by the Venda (40.7 g) with a similar mass (Appendix 4.9.). Furthermore, the Venda (40.7 g), Seshego (38.4 g) and Red (37.0 g) strain had a similar mass at harvest.

4.6. DISCUSSION AND CONCLUSIONS

4.6.1. Stocking density

The fish in the dome ponds were initially stocked at a density of 8 fish/m^3 (Appendix 4.2) and for the fish raised in the recirculation system at a stocking density of at least 16 fish/m^3. The two aquacultural production systems were not stocked at maximum full potential that is generally considered to be profitable (Palada-De Vera and Eknath, 1993; Hulata *et al.*, 1995 and Bentsen *et al.*, 1998).

The stocking densities that are generally used for aquaculture to realise a reasonable profit are as indicated in Table 4.2 for the different management systems.

Table 4.2. The stocking density in different production systems

Production unit	Stocking density	Reference
Extensive system	10 fish/m^2	Suresh and Lin (1992)
	2 fish/m^2	Bentsen *et al.* (1998)
		Mair *et al.* (1995)
Semi-intensive system	10 000 fish/ha	Lovshin *at al.* (1990)
		Soderberg (1997)
	2 500 fish/ha	Soderberg (1997)
	10 000 fish/ha	Soderberg (1997)
	20 000 fish/ha	Soderberg (1997)
	5 fish/m^2	Bentsen *et al.* (1998)
Intensive system	80 000 fish/ha	Soderberg (1997)
	51 fish/m^2	Mair *et al.* (1995)
	64 fish/m^2	Mair *et al.* (1995)
	10 – 200 fish/ℓ	Graham and Bakar (1999)

The difference in mass and length at stocking of the four strains of tilapia should not have influenced the final length attained at harvest as observed by Palada-De Vera and Eknath (1993) and Mair *et al.* (1995). Bentsen *et al.* (1998) indicated that age differences of more than two months at stocking of the grow-out phase did not affect body mass at harvest. Furthermore, Palada-De Vera and Eknath (1993) showed that groups of tilapia fry differing in mean size at stocking from 2.9 to 8.3 g did not differ significantly in body mass at harvest after three months of communal stocking. When a number of mature tilapia of both sexes are stocked in a spawning pond, their swim-up fry consist of groups of individuals of different ages

and sizes (Hulata *et al.,* 1986 and Coward and Bromage, 2000), due to the fact that groups of tilapia broodstock do not spawn synchronously but pairwise, preceded by nest digging, choice of mate and courtship (Hulata *et al.,* 1986; Bentsen *et al.,* 1998; Campos-Mendoza *et al.,* 2004 and Biswas *et al.,* 2005); the fingerlings initially stocked had different mass and total length at stocking.

Difference between the four strains at harvest was not influenced by the difference in mass, length and difference in stocking density.

4.6.2. Water quality and feed adjustment

Generally, the water quality parameters were within the range where *O. mossambicus* can grow normally (Soderberg, 1997; Macaranas *et al.*, 1997 and Linhesueh *et al.,* 2000), and the values were within a similar range in a particular production system. The communal way of stocking fish, as used in the GIFT project (Palada-De Vera and Eknath, 1993; Hulata *et al.,* 1995; Bentsen *et al.,* 1998 and Nguyen and Little, 2000), reduced the effect of variations in both systems used.

4.6.2.1. pH : Generally, the pH was within the range that is suitable for tilapia to grow according to Soderberg (1997) and Macaranas *et al.* (1997) i.e. within a range of 6.5 to 9.0 (Appendix 4.3).

4.6.2.2. Oxygen concentration: The oxygen concentration was more than 3.0 mg/ℓ for both the fish raised in the recirculating system and dome ponds (Appendix 4.4). The increase in oxygen concentration in the dome ponds in the afternoon was due to the oxygen released to the water by algae *via* the process of photosynthesis. However, the percentage oxygen saturation was roughly constant at approximately 50% saturation for fish raised in the recirculation system (Appendix 4.5.). Generally the oxygen concentration was above 3 mg/ℓ, which is considered to be suitable for tilapia to grow (Soderberg, 1997 and Macaranas *et al.,* 1997).

4.6.2.3. Temperature: The temperature was generally above 20 °C in all production systems throughout the grow-out phase, which is considered to be the lowest temperature at which *O. mossambicus* can grow (Macaranas *et al.,* 1997 and Linhesueh *et al.,* 2000). No significant differences in temperature were observed in both systems used (Appendix 4.5 and Appendix 4.11).

4.6.2.4. Un-ionised ammonia: The interaction between pH and temperature was used to estimate the un-ionised ammonia concentration (mg/ℓ) in the experimental units, following a procedure of Soderberg (1997). The estimated un-ionised ammonia concentration remained below the critical levels i.e. 0.02 mg/ℓ in the morning and 0.03 mg/ℓ in the afternoon for both the recirculating system and dome ponds. *O. mossambicus* has been found to die when exposed to an un-ionised ammonia level of 2 mg/ℓ (Suresh, 1999).

4.6.2.5. Feed adjustment: Feed was adjusted as indicated in Appendix 4.10 and 4.12. The food consumption and growth increases with temperature (Soderberg, 1997); therefore, temperature and genetic make-up were the major factors determining the growth performance of the four strains of tilapia. The effect of differences in water temperature between strains was reduced by means of communal stocking (Bentsen *et al.,* 1998). Therefore, only the genetic potential of strains was evaluated for their growth performance.

4.6.3. Mortality

A comparison of mortality was excluded due to the loss of strain identification markings as also previously reported by Palada-De Vera and Eknath (1993), Hulata *et al.* (1995), Bentsen *et al.* (1998) and Rowena *et al.* (1999).

4.6.4. Growth

4.6.4.1. Sex comparison: (i.e. comparison of males and female). The LSD for the comparison of the mean weight at harvest between males and females in the recirculation system (Appendix 4.5.) and dome ponds (Appendix 4.6.) indicated that the mean mass at harvest of male fish was significantly higher ($p \leq 0.05$) than that of females.

These results are in agreement with the outcomes of the research conducted by Lovshin *et al.* (1990), who found that males grew twice as much as females. Bentsen *et al.* (1998) observed that the overall female to male body mass was 0.65 for hybrids and 0.70 for purebred strains.

The difference between males and females in terms of growth performance agreed with the general findings that males grow significantly bigger than females regardless of the production system (Hulata *et al.*, 1995; Mair *et al.*, 1995; Marengoni and Onoue, 1998; Carrasco *et al.*, 1999; Chmilevskii, 1999; Rowena *et al.*, 1999 and Little *et al.*, 2003). There was an exception in the case of the Red strain males in the dome ponds, which showed a slightly lower body mass at harvest when compared to the females. Marengoni and Onoue (1998) reported that some research results indicated that male fish grew significantly faster than female fish even when reproduction was prevented.

4.6.4.2. Strain comparison: (i.e. regardless of sex) For the fish raised in the recirculating system and dome ponds, the difference in mean mass at harvest between the Zulu and Venda strains was similar ($p \leq 0.05$). However, the mean mass of the Zulu strain was significantly more than that of the Seshego and Red strains. When the four strains of tilapia are ranked according to the mass gained at harvest regardless of the production system, the following results were obtained: the Zulu strain ranked first, followed by the Venda, Seshego and Red strains.

Contrary to our results, different growth performance ranking orders of various strains of tilapia were obtained in different production systems by Hulata *et al.* (1995), Marengoni and Onoue (1998), Rowena *et al.* (1999), MÜller-Belecke and HÖrstgen-Schwark (2000) and Nguyen and Little (2000). According to Bentsen *et al.* (1998), the growth performance testing programme requires a strong similarity between the tested environments and the targeted farming conditions. This led to several hybrids or purebred strains being developed for diverse production systems, which was also confirmed by this study.

In conclusion, males were found to be bigger than females. This was observed during both the nursery and grow-out phases. The Zulu and Venda strain had similar mass at harvest. The Zulu strain was bigger than the Seshego and Red strains. The Venda strain had a mass that was similar to the Seshego and Red strains. This was generally observed during the grow-out phase. The above results might change if recommended stocking rates (from the literature) are used to compare these four strains.

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APPENDIXES

Table of contents page

Appendix 2.1. Schematic drawing of the breeding tunnel used during the fry production phase

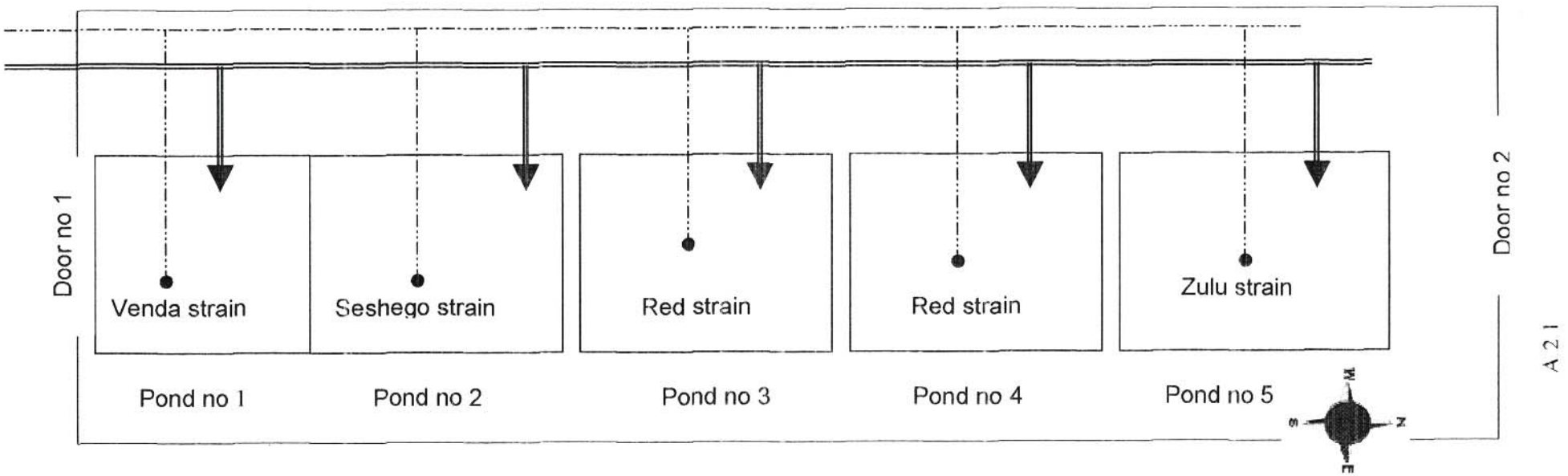


Figure 1. Schematic drawing of the breeding tunnel used for the breeding of four strain of Mozambique tilapia, *O. mossambicus*

Symbols used

Pipe supplying aged water from 4 x 15 m^3 storage tanks

Atmospheric air from a blower

Ponds size 25 m^2, 1m deep, sealed with 200 µm plastic liner

Appendix 2.2. One-Way Analysis of Variance for the daily pond water temperature used when breeding four strains of *O. mossambicus*

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains ponds	3	25.5257	8.50857	3.76*	2.46	4.14
Experimental error	64	114.831	2.26298			
Total	67	170.356				

Least Significant Difference (LSD)		
Variable (ponds)	**Mean temperature (°C)**	**Homogeneous Group**
Red	32.0	I
Seshego	32.0	I
Venda	30.9	I
Zulu	30.7	I
Critical T value of 1.998 at 5%		
Critical value for comparison 1.0308		
Standard error for comparison 0.5160		

Chapter 3

Appendix 3.1. Schematic drawing of the facilities that were used during the nursery phase

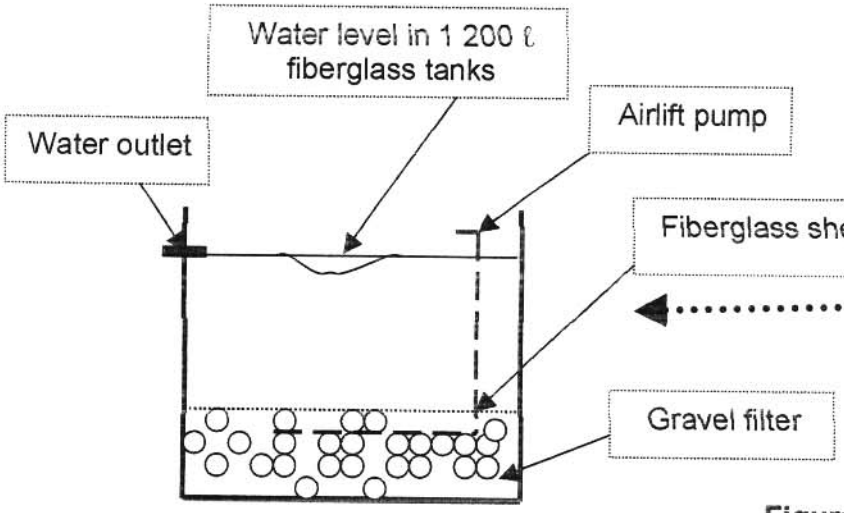


Figure A. Closed tank-recirculating system

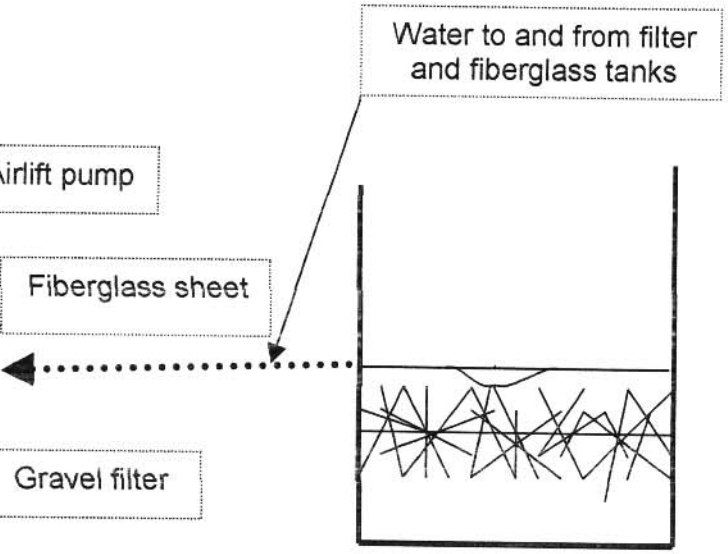


Figure B. Open recirculating system when all tanks are filtered through the same brush filter system

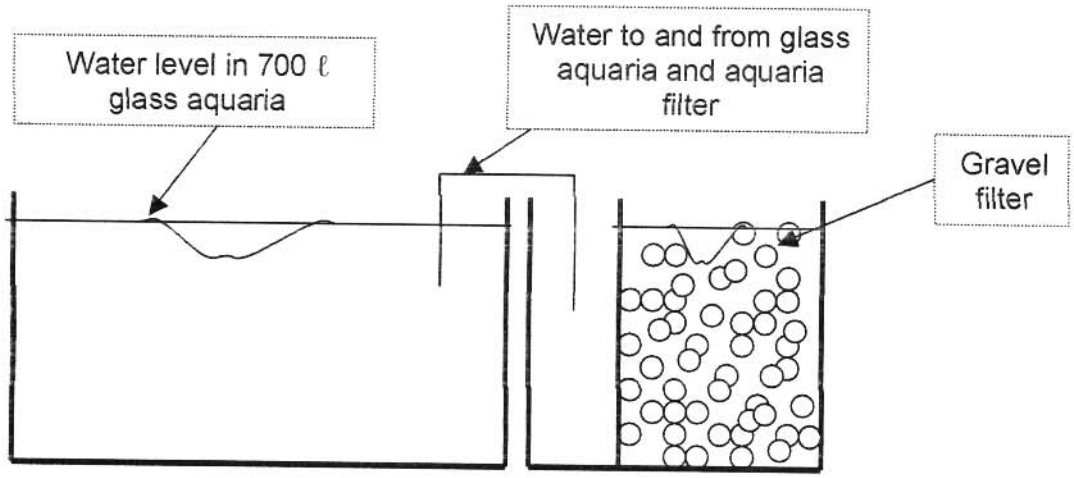


Figure C. Glass aquaria used during the nursery phase

Appendix 3.2. One-Way analysis of Variance for length at stocking during the nursery phase of four strains of *O. mossambicus* (Sample size of 100 were weighed (mm) as used for each strained)

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains	3	119.5	39.8333	7.75**	2.62	3.83
Experimental error	396	2034.34	513722			
Total	399	2153.84				

Least Significant Difference (LSD)		
Variable (Strains)	Mean length ± SD (mm)	Homogeneous Group
Venda	10.10 ± 2.27	I
Red	9.81 ± 2.18	I
Zulu	9.53 ± 2.45	I
Seshego	8.64 ± 2.13	I

Critical T value of 1.966 at 5%
Critical value for comparison 0.6302
Standard error for comparison 0.3205
SD = Standard deviation

Appendix 3.3. i. One-Way Analysis of Variance for the tank water temperature during the nursery phase of the four strains of *O. mossambicus*

Source of variation	Degrees of Freedom	Sum of Squares	Sum of Mean	F-Value		
				Computed	Tabular	
					0.05	0.01
Strains	8	37.5864	4.6983	0.96^{ns}	3.04	4.71
Experimental error	288	1480.17	5.13946			
Total	296	1517.75				

Appendix 3.3. ii. One-Way Analysis of Variance for the aquaria water temperature during the nursery phase of the four strains of *O. mossambicus*

Source of variation	Degrees of Freedom	Sum of Squares	Sum of Mean	F-Value		
				Computed	Tabular	
					0.05	0.01
Aquaria	10	55.9073	5.59073	2.52^{ns}	3.04	4.71
Experimental error	352	780.366	2.21695			
Total	362	836.274				

Appendix 3.4. One-Way Analysis of Variance for the mean mass of four strains of *O. mossambicus* raised in tanks during nursery phase

Source of Variation	Degree of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains	8	12713	89.12	134.79**	1.83	2.32
Experimental error	5075	59834.2	11.79			
Total	5083	72547.1				

Least Significant Difference (LSD)			
Variables Strains	Mean mass ± SD (g)	Sample size	Homogeneous Group
Venda tank 2	8.9 ± 5.04	n = 327	I
Venda tank 3	8.0 ± 5.01	n = 352	I
Venda tank 1	6.3 ± 2.23	n = 453	I
Zulu tank 3	5.3 ± 3.19	n = 300	I
Zulu tank 1	4.8 ± 2.95	n = 497	I
Seshego tank 1	4.3 ± 3.85	n = 927	I
Seshego tank 2	4.3 ± 3.59	n = 1194	I
Zulu tank 2	4.2 ± 2.82	n = 249	I
Red tank 1	3.3 ± 1.54	n = 778	I

Critical T value of 1.960 at 5%

Critical and standard values of differences vary between comparisons because of an unequal number of fish at harvest

SD = Standard deviation

Appendix 3.5. One-Way Analysis of Variance for the mean mass of four strains of *O. mossambicus* raised in aquaria during the nursery phase

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains	10	7304.54	730.454	51.46**	1.83	2.32
Experimental error	6234	88493.1	14.2952			
Total	6244	95797				

Least Significant Difference (LSD)			
Variables strains	Mean mass ± SD (g)	Sample size	Homogeneous Group
Venda 1	7.2 ± 4.80	n = 391	I
Venda 2	7.1 ± 5.02	n = 366	I
Venda 3	6.7 ± 4.71	n = 440	I
Zulu 1	4.9 ± 3.49	n = 434	I
Seshego 1	4.8 ± 4.17	n = 710	I
Seshego 3	4.7 ± 3.98	n = 857	I
Seshego 2	4.6 ± 4.00	n = 852	I I
Zulu 2	4.3 ± 3.10	n = 446	I I
Red 1	4.0 ± 2.45	n = 928	I
Zulu 3	4.0 ± 2.74	n = 380	I I
Zulu 4	3.0 ± 2.68	n = 442	I

Critical T value of 1.960 at 5%

Critical and standard values of differences vary between comparisons because of an un equalnumber of fish at harvest

SD = Standard deviation

Appendix 3.6. One-Way Analysis of Variance for the mean mass of male and female fish of the four strains of *O. mossambicus* raised in aquaria during the nursery phase

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains	7	6582.27	940.324	68.06**	2.09	2.8
Experimental error	4167	57567.9	13.8152			
Total	4174	64150.2				

Least Significant Difference (LSD)			
Variables strains	**Mean mass ± SD (g)**	**Sample size (n)**	**Homogeneous Group**
Venda Female	7.7 ± 5.89	n = 494	I
Venda Male	5.6 ± 1.83	n = 312	I
Zulu Male	5.6 ± 3.44	n = 470	I
Seshego Male	5.4 ± 4.86	n = 800	I
Red Male	4.2 ± 2.46	n = 450	I
Seshego Female	4.0 ± 2.87	n = 761	I
Red Female	3.9 ± 2.44	n = 478	I I
Zulu Female	3.8 ± 2.77	n = 410	I

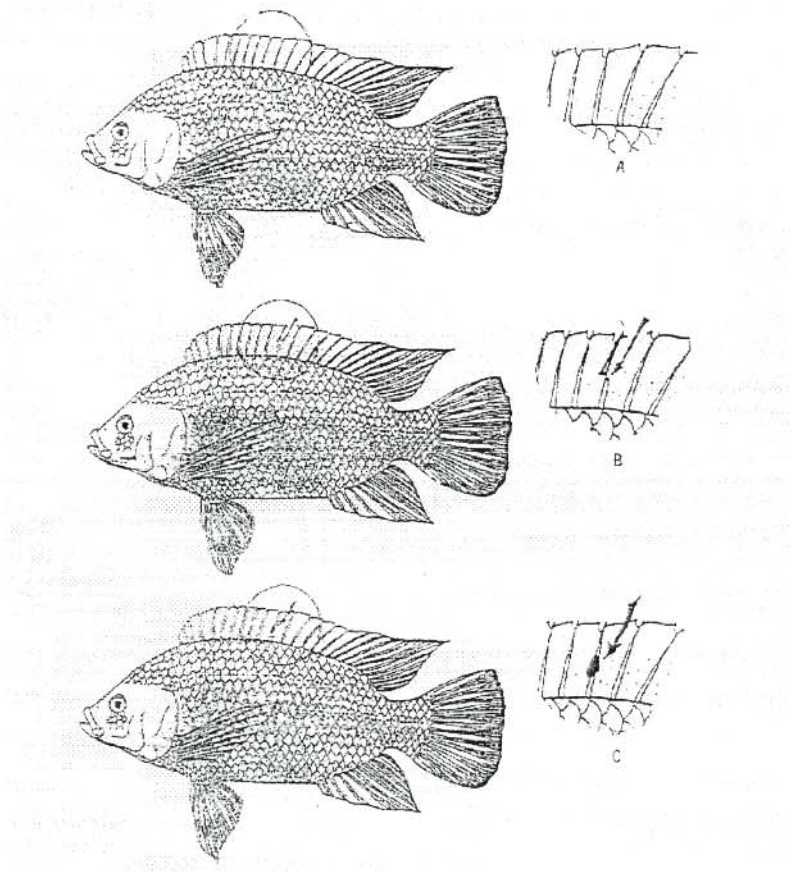
Critical T value *of 1.960* at 5%

Critical and standard values of differences vary between comparisons because of an unequal number of fish at harvest

SD = Standard deviation

Chapter 4

Appendix 4.1. Technique for dorsal fin spine marking of tilapia. A: Unmarked fin; B: Newly cut spine and C: Permanent mark developed by callus formation (from Khater, 1985)



Appendix 4.2. The stocking densities for the four strains of tilapia raised during the grow-out phase

Strains	Sex and pond number					
	Males			Females		
	Dp11	Dp13	Dp18	Dp12	Dp14	Dp15
Red	25	25	25	25	25	28
Seshego	25	25	25	25	25	29
Venda	25	25	25	25	25	25
Zulu	25	25	25	25	25	25
	Sex and tank number					
Strains	Males			Females		
	S2D1	S2D2	S2D3	S3D1	S3D2	S3D3
Red	63	61	61	36	59	58
Seshego	23	26	25	36	59	58
Venda	100	100	100	100	100	100
Zulu	99	100	100	100	100	100

Note that S2D2 identifies system two (2) tank two (2) and Dp11 identifies dome pond eleven (11)

Appendix 4.3. The pH range measured during the grow-out phase of the four strains

	Sex	Tank/Pond number	Morning		Afternoon	
			Min.	Max.	Min.	Max.
Recirculating system	Males	S2D1	5.81	6.66	6.72	6.77
		S2D2	5.81	6.65	6.71	6.76
		S2D3	5.84	6.71	6.84	6.96
	Females	S3D1	5.77	6.71	6.83	6.96
		S3D2	5.70	6.67	6.83	6.89
		S3D3	5.73	6.68	6.84	6.84
Dome ponds	Males	Dp11	6.37	7.63	8.03	8.43
		Dp13	6.29	7.69	8.09	8.49
		Dp18	6.37	7.91	8.03	8.15
	Females	Dp12	6.59	7.72	8.42	8.42
		Dp14	6.89	7.88	8.15	8.15
		Dp15	6.78	7.88	8.47	8.47

Note that S2D2 identifies system two (2) tank two (2) and Dp11 identifies dome pond eleven (11)

Appendix 4.4. The oxygen concentration (mg/ℓ) means and standard deviation, as well as percentage saturation obtained during the grow-out phase of the four strains of tilapia

	Sex	Tank/pond number	Morning		Afternoon	
			% saturation Mean ± SD	Concentration Mean ± SD	% saturation Mean ± SD	Concentration Mean ± SD
Recirculating system	Males	S2D1	49.9 ± 23.7	4.2 ± 2.0	49.2 ± 27.2	3.7 ± 2.3
		S2D2	51.1 ± 24.6	3.8 ± 2.2	51.2 ± 27.3	3.7 ± 2.0
		S2D3	52.8 ± 26.7	3.8 ± 1.5	50.9 ± 24.6	3.7 ± 1.7
	Females	S3D1	53.4 ± 24.0	3.9 ± 1.9	53.4 ± 22.4	4.0 ± 1.9
		S3D2	51.6 ± 24.9	5.7 ± 2.2	53.2 ± 23.8	3.9 ± 1.8
		S3D3	53.5 ± 25.6	4.0 ± 1.8	50.2 ± 22.3	3.4 ± 1.6
Dome ponds	Males	Dp11	54.6 ± 28.6	4.4 ± 2.3	69.7 ± 35.7	5.3 ± 2.9
		Dp13	53.1 ± 24.4	4.3 ± 2.0	66.9 ± 30.5	5.2 ± 2.6
		Dp18	56.0 ± 28.1	4.5 ± 2.3	63.7 ± 27.7	5.0 ± 2.3
	Females	Dp12	54.1 ± 26.1	5.3 ± 2.6	70.2 ± 31.6	5.5 ± 2.7
		Dp14	53.9 ± 24.8	4.2 ± 2.0	67.0 ± 29.9	5.0 ± 2.0
		Dp15	52.9 ± 28.7	4.3 ± 2.3	65.7 ± 30.5	4.9 ± 2.3

SD = standard deviation

Appendix 4.5. One-Way Analysis of Variance of the daily mean water temperature between six tanks used in a recirculating system during the grow-out phase

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Tanks	5	365.849	73.1697	0.71^{ns}	2.26	3.11
Experimental error	390	40305.3	103.347			
Total	395	40671.1				

Least Significant Difference (LSD)

Variable (Tanks)	Mean daily tank water temperature ± SD °C	Homogeneous Group
S2D2	23.5 ± 10.3	I
S2D1	23.5 ± 10.2	I
S2D3	23.4 ± 10.12	I
S3D1	22.3 ± 9.6	I
S3D2	21.7 ± 10.0	I
S3D3	21.0 ± 10.6	I

Critical T value of 1.966 at 5%

Critical value for comparison 3.4793

Standard error for comparison 1.7697

SD = Standard deviation

Appendix 4.6. The One-Way Analysis of Variance for the comparison of the mean mass of male and female *O. mossambicus* fish in the recirculating syste at harvest

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Between sexes	7	149599	21371.2	60.4**	2.03	2.69
Experimental error	603	213350	353.4			
Total	610	362948				

Least Significant Difference (LSD)		
Variable (Sex)	Mean mass at Harvest (g) ± SD	Homogeneous Group
Zulu Male	100 ± 27.2	I
Venda Male	86.6 ± 28.3	I
Seshego Male	80.0 ± 24.0	I
Red Male	63.0 ± 14.9	I
Red Female	58.4 ± 17.7	I
Venda Female	49.9 ± 12.2	I
Zulu Female	49.6 ± 11.1	I
Seshego Female	47.8 ± 14.2	I
SD = Standard deviation		

Appendix 4.7. The One-Way Analysis of Variance for the comparison of the mean mass of the four strains in the recirculating system at harvest

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains	3	8016.85	2672.28	4.57**	2.62	3.83
Experimental error	607	354931	584.73			
Total	610	362948				

Least Significant Difference (LSD)		
Variable Strains	Mean mass at Harvest (g) ± SD	Homogeneous Group
Zulu	80.0 ± 24.0	I
Venda	70.2 ± 31.5	I I
Seshego	67.1 ± 28.1	I
Red	60.6 ± 16.5	I

Critical T Value of 1.967 at 5%

Standard error and critical values vary between comaprisons because of the unequal number of fish at harvest

SD = Standard deviation

Appendix 4.8. The One-Way Analysis of Variance for the comparison of the mean mass of male and female fish in the dome ponds at harvest across the strain

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Between sexes	7	10260.6	2672.28	11.11**	2.03	2.69
Experimental *error*	314	41429.5	584.73			
Total	321	51690.1				

Least Significant Difference (LSD)

Variable Sex	Mean mass at Harvest (g) ± SD	Homogeneous Group
Zulu Male	52.8 ± 11.9	I
Venda Male	45.9 ± 18.4	I
Seshego Male	42.9 ± 12.2	I I
Red Female	38.6 ± 10.1	I I
Zulu Female	36.9 ± 10.3	I I
Venda Female	35.4 ± 10.3	I
Seshego Female	34.4 ± 8.5	I I
Red Male	33.8 ± 8.9	I

Critical T value of 1.968 at 5%

Standard error and critical values vary between comparison because of the unequal number of fish at harvest

SD = Standard deviation

Appendix 4.9. The One-Way Analysis of Variance for the comparing of mean mass of four strains in the dome ponds at harvest

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Strains	3	2303.5	767.835	4.94**	2.62	3.83
Experimental error	318	49386.6	155.304			
Total	321	51690.1				

Least Significant Difference (LSD)

Variable Strains	Mean mass at Harvest (g) ± SD	Homogeneous Group
Zulu	44.4 ± 31.5	I
Venda	40.7 ± 15.7	I I
Seshego	38.4 ± 11.1	I
Red	37.0 ± 9.9	I

Critical T Value of 1.967 at 5%

Standard error and critical values vary between comaprisons because of the unequal number of fish at harvest

SD = Standard deviation

Appendix 4.10. The average biomass and feed adjustments during the experimental period in the recirculation system

Sex	Tank number	Biomass and feed adjustments (g)							
		1st sampling		2nd sampling		3rd sampling		4th sampling	
		Biomass	Feed/day	Biomass	Feed/day	Biomass	Feed/day	Biomass	Feed/day
Males	S1DD1	1815.7	181.6	4372.5	437.3	7738.3	773.8	12521.9	1252.2
	S2D2	1658.4	165.8	5586.3	558.6	9036.4	903.6	13484.4	1348.4
	S2D3	1276.4	127.6	3501.3	350.1	5108.8	510.9	8375.1	837.5
Females	S3D1	1602.2	160.2	3506.7	350.7	5253.8	525.4	7392.5	739.3
	S3D2	1456.8	145.7	3337.2	333.7	4306.5	430.7	6289.8	629.0
	S3D3	1115.2	111.5	3553.3	355.3	4017.9	401.8	6326.7	632.7

Note that S2D1 identifies system two (2) tank one (1)

Appendix 4.11. One-Way Analysis of Variance for the six dome ponds mean water temperature used during the grow out phase

Source of Variation	Degrees of Freedom	Sum of Squares	Sum of Means	F-value		
				Computed	Tabular	
					0.05	0.01
Ponds	5	11.3268	2.26535	0.02^{ns}	2.26	3.11
Experimental *error*	396	37020.2	93.4853			
Total	409	37031.5				

Least Significant Difference (LSD)

Variable (Ponds)	Mean daily pond water temperature ± SD °C	Homogeneous Group
Dp15	21.2 ± 9.1	I
Dp13	21.1 ± 10.0	I
Dp12	21.1 ± 10.4	I
Dp11	20.9 ± 9.3	I
Dp14	20.8 ± 9.2	I
Dp18	20.7 ± 9.9	I

Critical T value of 1.966 at 5%

Critical value for comparison 3.2842

Standard error for comparison 1.67050

SD = Standard deviation

Appendix 4.12. The average biomass and feed adjustments during the experimental period in the dome ponds

Sex	Pond number	Biomass and feed adjustments (g)							
		1st sampling		2nd sampling		3rd sampling		4th sampling	
		Biomass	Feed/day	Biomass	Feed/day	Biomass	Feed/day	Biomass	Feed/day
Males	Dp11	746.8	29.8	2108.5	84.4	2903.1	116.2	3766.6	150.6
	Dp13	746.8	29.8	1627.6	65.1	1982.9	79.3	2170.0	86.8
	Dp18	804.2	32.2	1359.5	54.4	2178.7	87.2	1644.2	65.7
Females	Dp12	711.9	28.5	1600.8	64.1	1990.2	79.6	3312.2	132.6
	Dp14	743.9	29.7	1823.3	72.9	2482.0	99.3	2220.5	88.8
	Dp15	866.9	34.7	1869.4	74.7	2521.6	100.8	3427.4	137.1

Note that Dp11 identifies dome pond eleven (11)