Agricultural Sciences, 2022, 13, 897-915
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Suitable Temperature, Stocking Density and Feeding Rate for Optimal Growth of Sex Reversed Fry of Nile Tilapia *Oreochromis niloticus* (Senegal River Strain)

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How to cite this paper: Tine, M., Thiombane, A.B., Sonko, F., Ndiaye, N.D. and Diadhiou, H.D. (2022) Suitable Temperature, Stocking Density and Feeding Rate for Optimal Growth of Sex Reversed Fry of Nile Tilapia *Oreochromis niloticus* (Senegal River Strain). *Agricultural Sciences*, **13**, 897-915.
https://doi.org/10.4236/as.2022.137056

Received: April 14, 2022
Accepted: July 25, 2022
Published: July 28, 2022

Abstract

Determining the suitable fish farming conditions for optimal growth is necessary for aquaculture production, but it is not very obvious because it requires a good understanding of species biology. Thus, this study aims to evaluate the effects of different temperature regimes, stocking densities, and feeding rates on the growth of Nile tilapia, *Oreochromis niloticus* fingerlings that have been sex-reversed with 17α methyl testosterone. Three independent experiments were performed (with replicates) at the IRD Bel-Air fish farm (Dakar, Senegal) on 27-day-old fry maintained in six 25 L tanks with a batch of 100 individuals each. These fry were subjected to three different temperatures (26˚C, 28˚C, 30˚C; kept constant with thermostats), stocking densities (5, 10 and 15 ind/l) and feeding rates (5%, 10% and 15% of biomass; distributed three times a day). For the temperature and density treatments, fry was fed a pelleted feed containing 38% protein, distributed by hand at 10% of their total biomass, readjusted after each measurement. Growth performance (total weight, weight gain and daily weight gain), physicochemical parameters (temperature, oxygen, nitrite and phosphorus), feed conversion ratio (FCR) and survival rate (SR) were regularly monitored (weekly) during the experimental period. For the heat treatment, the results did not show an apparent relationship between growth performance and nitrite, phosphorus or dissolved oxygen (DO) contents. In contrast, there was a significant correlation between temperature and growth rates, with the best growth being obtained at 30˚C compared to 28˚C and 26˚C. Similarly, growth rates were correlated with stocking density and feeding rate but not with oxygen, temperature, ni-

trite or phosphorus levels. The best growth rates were observed at the lowest density (5 ind/l) and for the highest feeding rate (15% of biomass), which coincides with the best FCR and survival rates. Thus, 30˚C, 5 ind/l and 15% of biomass appeared to be the most favorable temperature, stocking density and feeding rate for optimal growth of Nile tilapia fry after inversion. The application of these results in the culture systems will allow to reach a good production of *O. niloticus* and thus to contribute to sustainable development of fish culture in Senegal.

Keywords

Density, Feeding Rate, Fry, Growth, Temperature, Nile Tilapia

1. Introduction

Fish is a very important global food resource, especially in Africa where it contributes to the nutritional security of 200 million people and provides more than 10 million incomes [1] [2]. Over the past five decades, global fish consumption has increased from 50 million tons (Mt) in 1980 to 131 Mt in 2011 [3]. Global per capita fish consumption has increased from 9.0 kg in 1961 to 20.0 kg in 2017. It is estimated at 20.5 kg in 2018 and is expected to reach 21.5 kg in 2030. In Africa, per capita fish consumption is projected to decline by 0.2 percent per year until 2030, raising serious concerns about food security. The global supply of fishery products for human consumption, estimated at 11.3 kg/person in 1980, reached a high of 18.8 kg/person in 2011 [3]. It has outpaced population growth with an average rate of 3.2% per year, doubling the population growth. Such a situation is mainly due to the decrease in the volume of fish catches, the decline of fish stocks and the increase in coastal populations, especially artisanal fishing communities. Therefore, meeting the fish needs of human populations remains difficult due to the shortage of fishery products, resulting from the overexploitation of natural aquatic resource stocks [4] [5] [6].

Faced with this difficulty in fish supply, aquaculture has emerged as an alternative to reduce the deficit in animal protein consumption [7] [8] [9]. Indeed, global aquaculture production contributed 44.1% to the total production of capture fisheries and aquaculture in 2014. For that same year, out of 580 species farmed, the 362 are fish including the Nile tilapia, *Oreochromis niloticus* [10]. In Senegal, fish farming has been of interest to decision-makers in recent years with a particular interest in *O. niloticus*, which is highly valued by local populations. This hardy species is fast growing [11] but shows sexual dimorphism in growth, with males growing better than females [12]. For example, a difference of 300 g was observed between male *O. niloticus* (700 g) and females (400 g) at one year of rearing [13]. Therefore, rearing mixed populations (males/females) is not economically viable [14] compared to rearing single male populations which is

economically more advantageous. Several techniques are then used to produce single-sex male populations, including hybridization, thermal method and hormonal treatment.

Although hybridization by crossbreeding of two different tilapia species can lead to a sex ratio change of 70% to 100% in favor of the male [15], a major drawback of this method is the difficulty to maintain pure lines of broodstock essential to obtain hybrids and the poor growth performance of hybrids resulting from these crosses. The thermal method which consists in applying a thermal shock to the eggs to reverse the sex of the larvae is efficient but very expensive and requires special knowledge. The production of single-sex male cohorts by steroidal hormone treatments is the most widely used method because of its effectiveness and reliability. This technique involves using the male hormone, 17-alpha-ethyltestosterone to produce male mono-sex populations. To do this, the fish feed is treated with the hormone and this treated feed is used to feed the fry shortly after hatching and throughout the period covering sexual differentiation. This technique is the most efficient and economical method to produce only male offspring and is therefore frequently used in tilapia rearing systems instead of the very time consuming, laborious and less accurate manual sex identification at early life stages.

The performance of aquaculture production can be influenced by sexual dimorphism, but also by genetic potential, fish feed and feeding, and rearing conditions, including salinity, pH, oxygen and temperature, etc. All of these factors affect the metabolism and growth of the fish, but temperature has undoubtedly the most critical effect. Stocking density is also a determining factor for the growth and productivity of fish in culture systems. Indeed, at low densities, aggressiveness and territoriality of populations can lead to increased mortality due to various injuries and infections, food wastage caused by monopolization of feeding areas by dominant individuals, which can lead to decreased fish growth and lower production [16]. As for high densities, they lead to a decrease in food availability and promote cannibalistic behavior [17]. Therefore, knowledge of the optimal stocking density is crucial to optimize the productivity of *O. niloticus* in culture systems. Another important factor for aquaculture production is fish feed and feeding habit, which can have a huge impact on Nile tilapia production. This is because feed provides the nutrients and energy needed for maintenance and growth of the fish, which usually spend a considerable amount of time on feeding to cover current energy costs and to build up energy reserves.

The objective of this study was to determine the optimal temperature, proper feeding rate and stocking density for improved growth of sex-reversed fry of a Senegalese strain of Nile tilapia *O. niloticus*. The mono-sexual male population used in this study was obtained by hormonal treatment with 17α-methyl testosterone (60 mg) mixed with feed and administered to fry shortly after hatching for a period of 90 days. The effects of temperature and feeding rate on growth performance were tested separately on fry distributed in 6 tanks per treatment at

an initial density of 100 larvae per tank. These experiments were performed with three temperature regimes (26˚C, 28˚C and 30˚C) and three feeding rates (5%, 10% and 15% of the total weight of individuals). The stocking density treatment was performed with three densities (5 ind/l, 10 ind/l and 15 ind/l). For each treatment, the experiment was carried out with replicates for a period of two months. The results obtained are encouraging and can contribute to improve the productivity of *O. niloticus* in semi-intensive farming systems.

2. Materials and Methods

2.1. Study Area

The experiments were carried out in the Centre for Oceanographic Research of Dakar-Thiaroye (CRODT) fish greenhouse on the campus of the Research Institute for Development (IRD) in HannBel-Air, Dakar Senegal. The fish greenhouse includes different aquaculture installations divided into different circuits (A, B, C, D and O) (Figure 1) made up of tanks and aquariums of different sizes that serve for different rearing operations (conditioning broodstock, sexual inversion, fattening of the fry which have left the inversion table, stabling of the male broodstock and, breeding and eggs hatching). These different installations are supplied with oxygen by an air compressor collected to bubblers, which is a source of oxygen for the fish.

2.2. Experimental Design

The experiments consisted of evaluating the effects of different temperatures, stocking densities and feeding rates on the growth of *O. niloticus* fry of a Senegal River strain. For each treatment (temperature, stocking density or feeding rate), experiments were performed in replicate on a male mono-sex population obtained by hormonal injection of 17*α*-methyl-testosterone (60 mg). This masculinizing hormone was mixed with 500 ml of an ethanol solution, poured onto one kilogram of food and the mixture was then stored in a cool place (4˚C) for 90

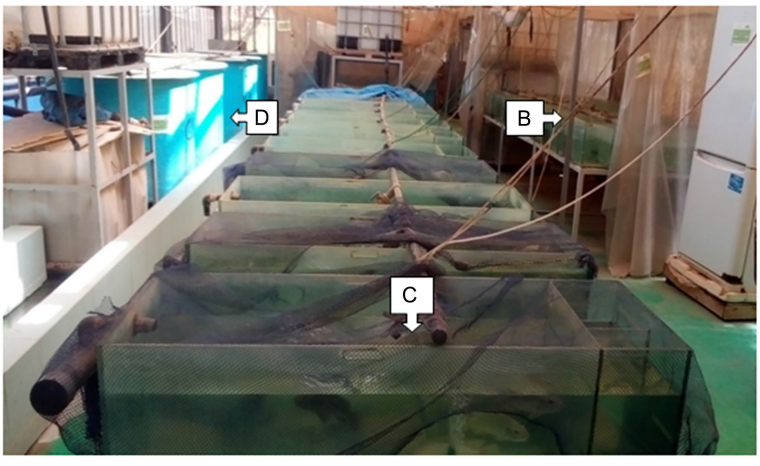

Figure 1. Interior of the IRD Bel-Air greenhouse showing circuits B, C and D.

days. This processed food was used to feed the fry shortly after hatching for a period of 28 days in order to have an all-male population. A total of 1200 fry in 6 × 20 L rearing tanks, with 100 fry per tank, were used for each treatment. Each rearing tank is equipped with an oxygenation device (bubblers) allowing a sufficient supply of oxygen.

The heat treatment was performed on six batches of 100 fingerlings kept at three different temperatures: 26˚C (TB1), 28˚C (TB2) and 30˚C (TB3). Temperatures for this treatment were kept constant using immersion heaters throughout the two-month experiment. The stocking density treatment was also performed on 6 batches of fry (batch 1 to batch 6) maintained at three different stocking densities: 5 ind/l (DB1), 10 ind/l (DB2) and 15 ind/l (DB3). The feeding rate treatment was conducted for a period of 2 months with three different rates: 5% (RB1) 10% (RB2), 15% (RB3) of the total body weight of individuals. Temperature and oxygen were measured twice daily (morning at 9:00am and evening at 3:00pm) using an OXI 330i/SET multifunction oximeter. Nitrite (NO_2^-) and phosphorus concentrations were measured once throughout the experiment using a HANNAN HI 83203 multi-parameter photometer. The water in the ponds was renewed every week at 1/4 of the total volume and the amount of water lost during siphoning was replaced.

2.3. Feeding Regime and Feed Conversion Ratio

For the temperature and stocking density experiments, fry were fed a commercial pelleted feed containing 38% protein, distributed in three daily meals. The daily feeding rate was set at 10% of the total fish biomass and was readjusted after each control fishing (15 days of rearing). For the feeding rate treatment, three feeding rates of 5%, 10% and 15% of the total body weight of the fish were used and distributed three times a day. For all treatments, the aquaria were siphoned off 2 hours after each feeding using a hose to collect the remaining uneaten food. Special care was taken to prevent larvae from passing through the hose. The remaining food collected by siphoning was then placed in tubes, dried and weighed using a 0.5 g precision sartorius scale to estimate the amount ingested by the fry. This was used to assess the efficiency of feed conversion, by calculating the ratio of dry weight of feed consumed to weight gain achieved during the experimental period. The feed conversion ratio (FCR) was calculated using the following formula:

$$\mathrm{FCR} = \frac{\mathrm{WG}}{\mathrm{FI}} \times 100$$

with WG = weight gain and FI = feed intake (g).

Dead fish were identified and their number estimated daily. The mortality data for each treatment were recorded in an Excel file for the estimation of the survival and mortality rates at the end of each experiment. The survival rate (SR) was calculated for each experiment using the following formula:

$$SR = \frac{NF}{NI} \times 100$$

with NF = final number of individuals and NI = initial number of individuals.

The average weight (AW) for each treatment was obtained using the following formula:

$$AW = \frac{TBW}{N}$$

with TBW = Total body weight) and N = number of individuals.

As different stocking densities with mortality rates were tested in this study, the weight gain (WG) calculation was done as follows:

$$WG(g) = FBW - IBW$$

with FBW = average final body weight and IBW (g) = average initial body weight (g).

Daily weight gain (DWG) allows to assess the daily weight gain of a farmed fish. It was estimated using the following formula:

$$DWG(mg/ind/d) = \frac{FBWG - IBW}{RT}$$

with FBWG = final body weight gain, IBW = initial body weight and RT = rearing time.

The significance of differences between means of the above parameters was verified using the Student's t-test. All analyses were completed using the "ADE4" library in "R" software. The significance level is set to 5%.

3. Results

3.1. Physicochemical Parameters

Tanks TB1, TB2, and TB3 correspond to the heat treatments where temperatures were kept constant at 26˚C, 28˚C, and 30˚C, respectively, using adjustable thermostats throughout the experiment. For the stocking density treatment, the temperature in the tanks was not held constant with thermostats. Variations in average temperature with time in tanks DB1, DB2, and DB3 are shown in **Figure 2(a)**.

In all tanks of the stocking density treatment, the average temperature was significantly higher at the beginning of the experiment during the first week (29.50 ± 1.50, 29.75 ± 1.75, and 29.75 ± 1.75 for DB1, DB2, and DB3, respectively) and lower at the end (22.20 ± 2.25, 22.25 ± 2.15, and 22.51 ± 2.23 for DB1, DB2, and DB3, respectively) (**Figure 2(a)**). Comparison of mean temperature shows that there were no significant differences between pools at the beginning and at the end of the experiment (Student's test; $p > 0.05$).

For the feeding rate treatment, the mean temperature in RB1, RB2, and RB3 tanks during the first two weeks of the experiment was 29.67˚C ± 0.07˚C,

29.55˚C ± 0.05˚C, and 29.60˚C ± 0.01˚C, respectively, whereas it was 22.32 ± 0.02, 22.36 ± 0.05, and 22.61 ± 0.05 in the same tanks at the end of the experiment (**Figure 2(b)**). During the first two weeks, the average temperature in these tanks was constant at 29˚C - 30˚C, then it started to decrease to a minimum of 22˚C at the end of the experiment (**Figure 2(b)**). Comparison of the average temperatures did not show significant differences between RB1, RB2, and RB3 at the beginning and end of the experiment (Student's t test; $p > 0.05$).

The heat treatment showed average oxygen content of 12, 10 and 9 mg/l for TB1, TB2 and TB3, respectively (**Figure 3(a)**). The oxygen content decreased slightly with time for all temperatures but there was no significant difference between TB1, TB2 and TB3. The oxygen content of the stocking density treatment showed a similar pattern. It decreased when the density increase (12.20, 10.26, and 9.25 mg/l for DB1, DB2, and DB3, respectively) (**Figure 3(b)**). It reached a minimum of 6 mg/l at the end of the experiment. The average DO content in RB1, RT2 and RT3 was 9.90, 10.03 and 9.91 mg/l, respectively (**Figure 3(c)**). It decreases with time and has a similar pattern for all three recharge rate treatments. No significant difference in average DO was observed between RB1, RB2, and RB (Student's t test; $p > 0.05$).

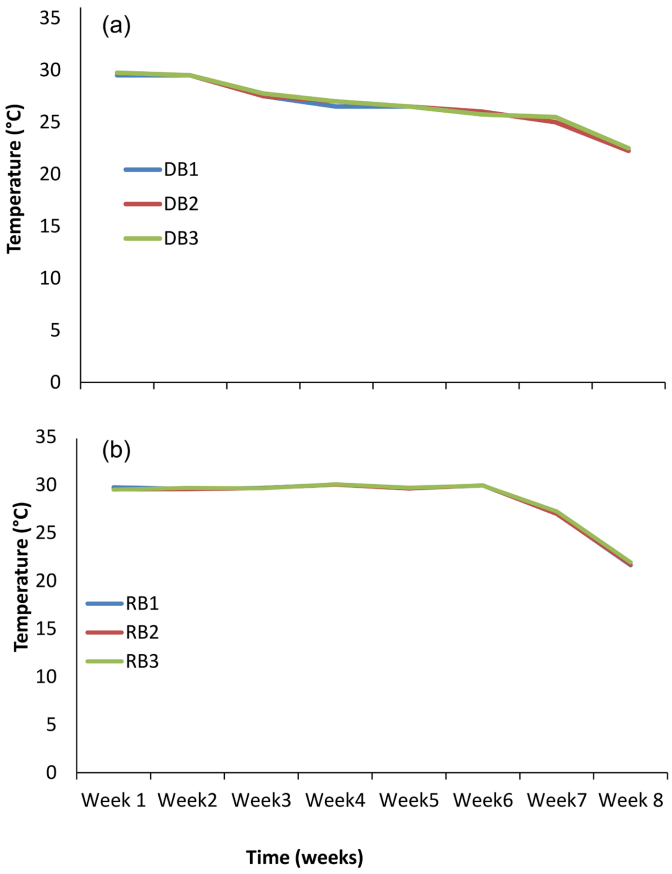

Figure 2. Variations of temperature in the rearing tanks of *O. niloticus* kept at different stocking densities (a) and fed with different feeding rates (b).

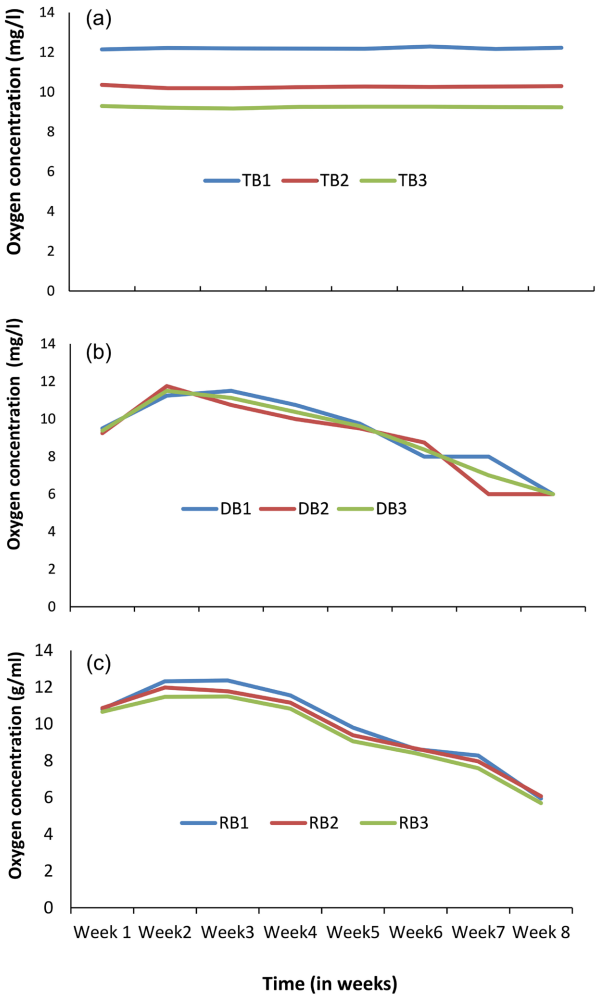

Figure 3. Variations of oxygen levels in the culture tanks of *O. niloticus* fry subjected to different temperature (a), stocking density (b) and feeding rates (c) treatments.

Table 1 shows the nitrite and phosphorus levels at the second estimate during the experimental period. The nitrite level was 0.12, 0.13 and 0.12 mg/l for TR1, TR2 and TR3, respectively. For stocking density treatment, it was 0.15, 0.14 and 0.15 mg/l in DB1, DB2 and DB3 tanks, respectively, while that for feeding rate treatment was 0.1, 0.07 and 0.09 mg/l for RT1, RT2 and RT3. Nitrite level was not significantly different between tanks regardless of treatment type (temperature, stocking density or feed rate) (Student's t-test; $p > 0.05$).

Phosphorus level was 0.86 mg/l for TB1, 0.65 mg/l for TB2 and 0.83 mg/l for TB3 (Table 1). For density treatment, it was 0.91, 1.23, and 0.60 mg/l for DB1, DB2, and DB3 tanks, respectively. For the feeding rate treatment, the phosphorus level was 0.93, 0.71 and 0.79 mg/l for RB1, RB2, and RB3, respectively. There was no obvious relationship between nitrite concentration and temperature, stocking density, or feed rate. Similarly, there was no apparent relationship between phosphorus concentrations and water temperature, stocking density, or feeding rate.

3.2. Feed Conversion Rate (FCR) and Survival Rate

The average FCR was 1.226 ± 0.898, 1.242 ± 0.752 and 1.286 ± 0.7980 for TB1, TB2 and TB3, respectively (Table 2). For stocking density treatment, the average FCR was 1.570 ± 0.975, 1.500 ± 0.860 and 1.327 ± 0.596 for DB1, DB2 and DB3, respectively (Table 2). No significant difference in FCR was observed between tanks for the temperature and stocking density treatments. The average FCR was 0.635 ± 0.210 for RB1 whereas it was 0.886 ± 0.284 and 1.348 ± 0.908 for RB2 and RB3, respectively (Table 2). The FCR was significantly higher for RB3 compared to RB1 and RB2 (Student's t-test; $p < 0.05$).

The survival rate was 83% - 97%, 86% - 94% and, 70% - 100% for temperature, feeding rate and stocking density treatments, with an average of 91.3%, 91.3% and 70%, respectively (Table 3). The survival rate was significantly lower for the lowest temperature (26˚C) and feeding rate (5% of the body weight) (Table 3) (Student's test; $p < 0.05$). On the other hand, it was higher for the lowest density (5 ind/l). The mortality rate for all three treatment types varied between 3% (TB) and 30% (DB3). It was lower for the highest temperature (30˚C) and high for the highest density (15 ind/l) (Table 3) (Student's t-test; $p < 0.05$).

Table 1. Nitrite and phosphorus content in the rearing tanks.

Treatment	Temperature			Stocking density			Feeding rate		
	TB1	TB2	TB3	DB1	DB2	DB3	RB1	RB2	RB3
Nitrite (mg/l)	0.115	0.13	0.115	0.11	0.065	0.090	0.150	0.140	0.145
Phosphorus (mg/l)	0.860	0.650	0.830	0.925	0.710	0.785	0.910	1.225	1.120

Table 2. Feed conversion ratio (FCR) of *O. niloticus* fry subjected to different temperatures, stocking densities and feeding rates.

Treatment	Temperature		Stocking density		Feeding rate	
Estimation	Tank	FCR	Tank	FCR	Tank	FCR
	TB1	0.220	DB1	0.710	RB1	0.785
1st estimation	TB2	0.420	DB2	0.850	RB2	0.610
	TB3	0.160	DB3	0.740	RB3	0.690
	TB1	0.600	DB1	0.840	RB1	0.290
2nd estimation	TB2	0.735	DB2	0.640	RB2	0.635
	TB3	0.945	DB3	0.850	RB3	0.730
	TB1	1.550	DB1	1.570	RB1	0.820
3rd estimation	TB2	1.435	DB2	1.680	RB2	1.000
	TB3	1.815	DB3	1.485	RB3	1.075
	TB1	2.535	DB1	3.160	RB1	0.645
4th estimation	TB2	2.380	DB2	2.830	RB2	1.300
	TB3	2.225	DB3	2.235	RB3	2.900
Average	TB1	1.226 ± 0.898	DB1	1.570 ± 0.975	TB1	0.635 ± 0.210
	TB2	1.242 ± 0.752	DB2	1.500 ± 0.860	RB2	0.886 ± 0.284
	TB3	1.286 ± 0.798	DB3	1.327 ± 0.596	RB3	1.348 ± 0.908

Table 3. Survival and mortality rates of *O. niloticus* fry subjected to different temperatures, stocking densities and feeding rates.

Tanks	Initial number	Final number	Survival rate (%)	Mortality rate (%)
TB1	200	166	83	17
TB2	200	186	94	6
TB3	200	194	97	3
	Average		91.3	8.6
RB1	200	172	86	14
RB2	200	188	94	6
RB3	200	188	94	6
	Average		91.3	8.6
DB1	200	200	100	0
DB2	400	356	89	11
DB3	600	420	70	30
Average			70.0	30.0

3.3. Growth Performances

The average weight of fry subjected to different temperatures, after two weeks in the rearing tanks, increased with time regardless of the temperature considered. It also increased with temperature, with the highest mean weight recorded at the highest temperature (30˚C) at the first estimate. Mean weight did not differ significantly between fry maintained at 26˚C and 28˚C in the first and second estimates (**Figure 4(a)**) (Student's t test; $p > 0.05$). However, it was significantly higher at 28˚C than at 26˚C at the 3rd and 4th estimates. Comparison of average weight gain showed an increase with temperature. The best WG for the temperature treatment was obtained at 30˚C at the 1st estimate compared to 26˚C and 28˚C (Student's t test; $p < 0.05$), which did not show significant differences (**Figure 4(b)**). In contrast, from the 3rd estimate, DWG was significantly higher for 28˚C compared to 26˚C. The average DWG after two months of experiment was significantly higher at 30˚C compared to 26˚C and 28˚C (**Figure 4(c)**) (Student's t test; $p < 0.05$). However, the differences in DWG between these three temperatures are more pronounced from the 2nd estimate onwards.

Overall, mean weight is higher at the lowest stocking density (5 ind/l) from the first estimate (**Figure 5(a)**). Variations in mean WGwith density showed the best growth performance in fry subjected to 5 ind/l, then 10 ind/l and 15 ind/l (**Figure 5(b)**) (Student's t test; $p < 0.05$). However, the differences between 10 ind/l and 15 ind/l were only significant at the 1st and 2nd estimates. No significant differences were observed between these two densities at the 3rd and 4th estimates (Student's t test; $p > 0.05$). Overall, the average DWG was higher in fry subjected to the lowest density, 5 ind/l ((DB: 100 individuals), followed by 10 ind/l (DB2: 200 individuals) and then 15 ind/l (DB3: 300 individuals) (**Figure**

5(c)) (Student's t test; $p < 0.05$). For the first two estimates, the individual weight of the 10ind/l treatment was significantly higher than that of the 15 ind/l treatment. However, no significant difference was observed in the 3rd and 4th estimates (Student's t test; $p > 0.05$). The mean weight increased with the estimates, regardless of the density considered.

The variation of mean weight with feeding rate showed an increase over time regardless of the diet considered (Figure 6(a)). Mean weight was higher for the highest feeding rate (15% of body weight) compared to 5% and 10% for all estimates (Student's test; $p < 0.05$). The mean weight of fry fed with a 10% feeding rate was significantly higher than that of fry treated with a 5% feeding rate at the 2nd, 3rd and 4th estimates (Student's t test; $p < 0.05$). However, no significant difference in mean weight was observed between these two feeding rates at the 1st estimate (Student's t test; $p > 0.05$). Similarly, mean WG (Figure 6(b)) and DWG

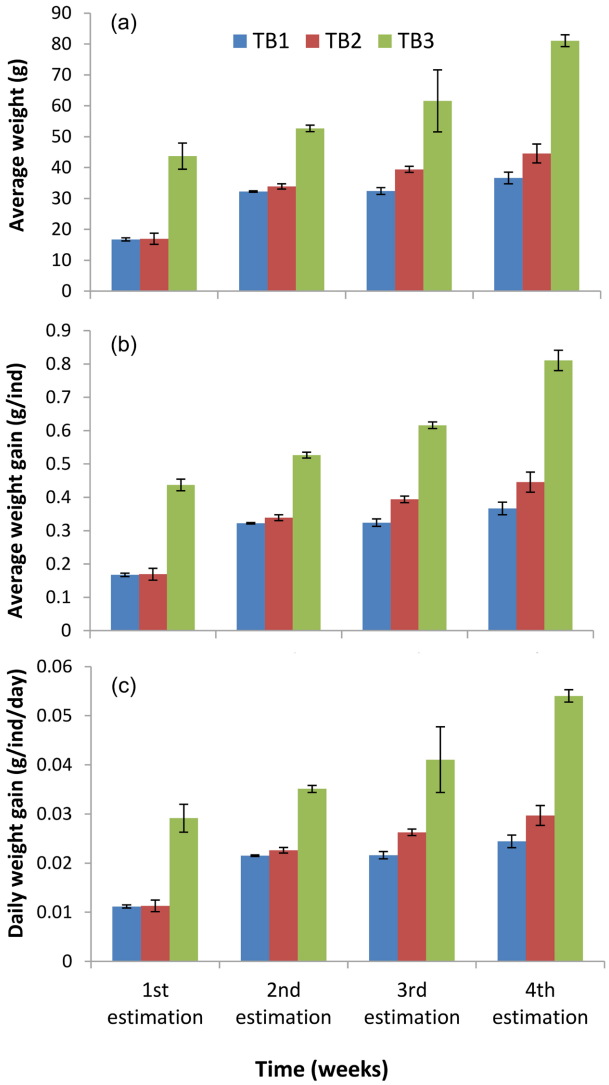

Figure 4. Average weight (a), weight gain (b) and daily weigh gain (c) of *O. niloticus* fry subjected to different heat treatments.

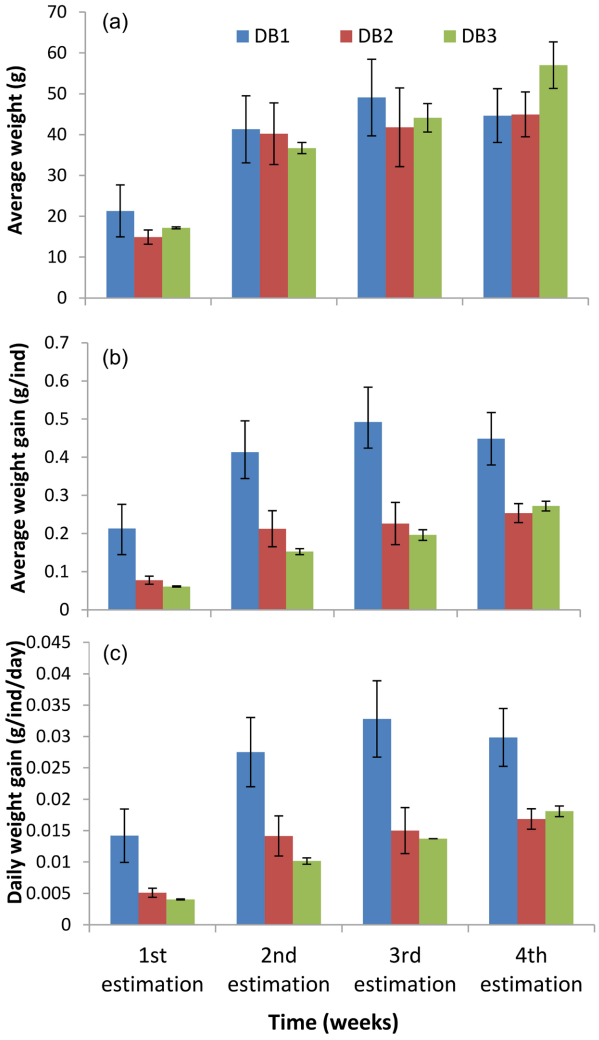

Figure 5. Average weight (a), weight gain (b) and daily weigh gain (c) of *O. niloticus* fry maintained at different stocking densities.

(**Figure 6(c)**) were higher for the 15% feeding rate compared with the 5% and 10% rates for all estimates (Student's t test; $p < 0.05$). No differences in individual weight and WG were observed between fry fed with 5% and 10% feeding rate in the 1st estimates (Student's t test; $p > 0.05$). In contrast, these were higher for fry fed with 10% compared to 5% at the 2nd, 3rd and 4th estimates (Student's t test; $p < 0.05$).

4. Discussion

Temperature and DO can influence the diet of fish and their desire to forage for food [18]. They can also influence the way food is processed and digested, as well as the absorption of nutrients by the gastrointestinal tract [18] [19]. Elevated temperatures and DO levels tend to increase food intake, metabolic performance and growth [18]. The results of this study show a higher average DO level for the temperature treatment: 12.20, 10.26 and 9.25 mg/l for 26˚C, 28˚C

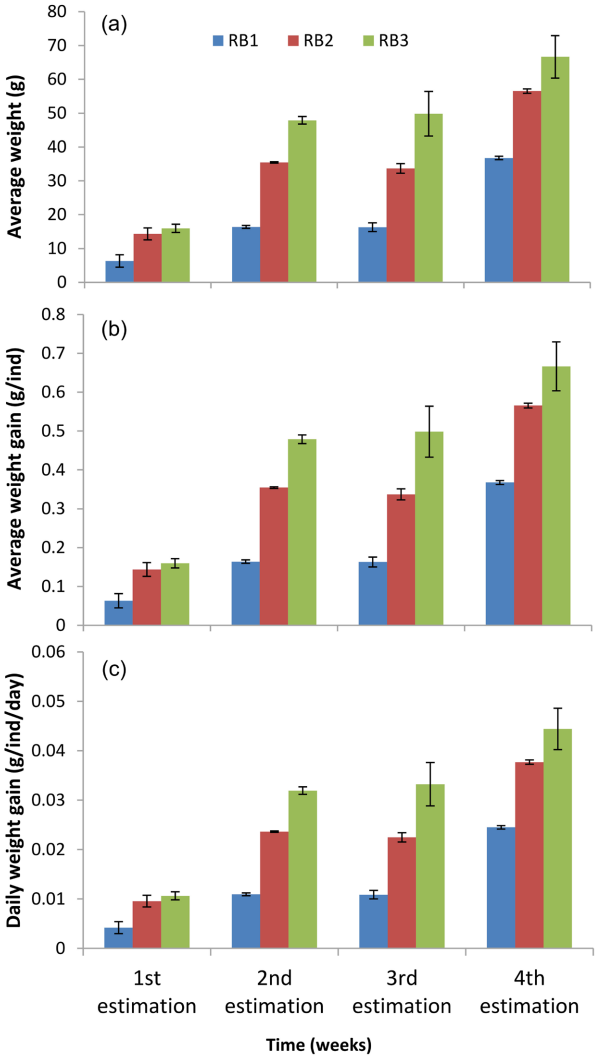

Figure 6. Average weight (a), weight gain (b) and daily weigh gain (c) of *O. niloticus* fry fed with different feeding rates.

and 30˚C, respectively. The oxygen level decreased during the experiment period to a minimum of 6 mg/l at the end of larval rearing. The results also show a significant correlation between temperature and DO, with the lowest oxygen levels occurring at the highest temperatures. The low oxygen levels at 26˚C could reflect higher food intake by fry maintained at this temperature, which could lead to a much higher metabolism and better growth performance. However, the best growth was not recorded at 26˚C but at 30˚C. This indicates that differences in DO levels do not reflect differences in its utilization for metabolic activities and fish growth. These would certainly reflect differences in water temperature. Indeed, it has been shown that metabolic activity and the desire to feed increase with temperature to an optimum that corresponds to both best growth and best food utilization [20].

The results of the stocking density and feeding rate treatments show relatively

constant temperatures around 29˚C - 30˚C at the beginning of the experiment which coincides with the warm period in the country. The drop in temperature from 29˚C to 22˚C at the end (third week) of larval rearing is due to changing weather conditions. Indeed, this temperature drop coincides with the beginning of the cold season (November) when temperatures are lowest. However, this seasonality does not seem to affect the growth of *O. niloticus* fry subjected to different stocking densities and feeding rates. Indeed, the temperatures recorded in this study fall within the range favorable for optimal growth of the species [21]. Indeed, *O. niloticus* prefers temperatures ranging from 14˚C to 35˚C although it can withstand below 7˚C and above 41˚C for several hours [22]. According to Azaza [23] the optimal temperature for growth of *O. niloticus* is between 27˚C and 30˚C. In the tropical region, *O. niloticus* can undergo great spatial and temporal variations in temperature [24]. For example, in the cold season, the species can encounter low temperatures (26˚C - 22˚C) while in the warm season it can encounter high temperatures (28˚C - 34˚C) [24] [25] [26] [27] [28]. It can even withstand cold temperatures (17˚C - 24˚C) and hot temperatures (over 40˚C) depending on the amplitude of the variations [24] [27] [28].

The high oxygen levels (9 - 11 mg/l) observed in the different stocking densities and feeding rates at the beginning of larval rearing could be explained by poor fish metabolism. The decrease in oxygen level from 9 mg/l (at the fourth week) to 6 mg/l (at the end of the experiment) could be explained by its massive use for metabolic activities of the fly, whose energy requirement increases during its growth. This increase in energy requirement will lead to an increase in cellular metabolism and thus to a consumption of oxygen. This oxygen is provided by respiration, a metabolic process that allows the production of energy necessary for the functioning of organisms by the oxidation of organic carbon. However, DO levels in the stocking density treatment are much higher than the amount needed (3 to 5 mg/l) for optimal tilapia growth [21]. Also, in this experiment, there were no large variations in nitrite or phosphorus levels that would influence fry growth.

The lowest survival rate (94.5%) of *O. niloticus* fry was observed at the 1st estimate compared to the 2nd, 3rd and 4th where the survival rate was 98.94%, 98.75% and 98.73%, respectively. The survival rates of the stocking density 15 ind/l were also lower compared to those recorded for 10 ind/l and 5 ind/l. These results could be explained by the fact that, at this stage, the fry are not yet well adapted to the new untreated feed that was used in replacement of the 17α-MT treated feed. Indeed, fry were weaned from a 17α-MT treated diet to a hormone-free diet and transferred from aquaria to 25 L tanks. The considerable increase in survival rate (about 98%) at the next three estimates can be explained by the absence of external stress as the fry are accustomed to the new diet and well adapted to their new environment. The relatively lower survival rate at the 1st estimate may also be due to cannibalism which can lead to high mortalities, in

agreement with the results of Campbell [29], who argues that cannibalism can significantly reduce the survival rate of *O. niloticus*.

The average growth rate of fry subjected to the different temperature treatments (26˚C, 28˚C and 30˚C) was highest at 30˚C. This rate increased significantly (from 397.3 to 736.8 g/d) over time between the 1st and 4th estimates. However, this increase in average growth rate over time is less pronounced at 28˚C and 26˚C (323.9 - 405.0 g/d and 306.4 - 333.2 g/d, respectively). Thus, 30˚C appears to be the optimal temperature for growth of post-inverted *O. niloticus* fry. It is then followed by 28˚C for which the highest growth rates (405.0 g/J) were obtained compared to 26˚C (333.2 g/J). Average WG showed a similar pattern with higher values recorded at 30˚C, followed by 28˚C and 26˚C. It also increased significantly from the 1st to the 2nd estimates. It also increased significantly from the 1st to the 4th estimate for 30˚C (43.7 - 81.05 g), 28˚C (16.95 - 44.55 g) and 26˚C (16.75 - 36.65 g). These results also indicate that 30˚C is the optimal temperature for growth of *O. niloticus* fry. This is in agreement with previous results that the optimal temperature for growth of this species ranges from 26˚C to 30˚C [30] [31] [32]. These differences in growth would not be due to competition for food or stress caused by siphoning off the remaining food. Instead, they could be explained by the action of temperature on the food requirement of fish, which increases with temperature.

The results of this study show that the stocking density 5 indiv/l is the optimal density for better growth of the *O. niloticus* Senegal River strain after sexual inversion with 17α-MT. The growth performance of *O. niloticus* at different stocking densities shows higher individual WG and DWG at the lowest density (5 indiv/l) compared to 10 indiv/l and 15 indiv/l densities. These results suggest that at low densities, all fish exploit the available food resource in the rearing tanks, in contrast to when stocked at high densities. This is in agreement with the fairly high FCR, which reflects efficient use of food for optimal growth. These results are consistent with previous studies that showed an effect of stocking density on growth performance of tilapia *O. niloticus* [33] [34] [35]. The results of the diet treatment show that individual WG during the entire experimental period is significantly higher for 15% (7 - 180.05 g) compared to 10% (which is the second most effective rate: 7.5 - 154.8 g) and then 5% (9 - 85.25 g). They also show that the average FCR is significantly higher for the 15% rate (FCR = 2.9), followed by 10% (FCR = 1.3) and finally 5% (FCR = 0.65). These FCR results reflect a feeding rate that clearly exceeds the metabolic needs of the individuals. Thus, the optimal feeding rate for Nile tilapia fry after inversion is 15% of the biomass corresponding to the best FCR. However, for efficient food utilization, the feeding rate of 10% is still the best, although its growth is lower than that of 15%. There are fewer food scraps, which is probably due to a low daily intake that does not meet the metabolic needs of the individuals. In summary, the best growth of fry occurred at the 15% feeding rate, which is effective but not efficient because the amount of leftover food is greater compared to the

other feeding regimes. Thus, the 10% feeding rate was found to be the most adequate rate for effective and efficient use of feed. The 5% feeding rate was not conducive to good growth and resulted in more mortalities due to cannibalism or other factors in the rearing environment. This interpretation corroborates previous results that insufficient food can induce size heterogeneity in fish leading to a high rate of cannibalism [36].

5. Conclusion

The objective of this study was to improve the productivity and competitiveness of the tilapia value chain through sustainable production of mono-sexual male fry via hormonal sex reversal using 17*α* methyl-testosterone. The results showed an effect of temperature on the growth of a strain of *O. niloticus* from the Senegal River. Indeed, the growth monitoring that was performed for two months showed that 30˚C is the optimal temperature for better growth compared to 28˚C and 26˚C. The results also indicate that stocking density is a determining factor for the growth and production of the species. Suboptimal densities can lead to the competition for food and space, cannibalism or food waste. Thus, 5 ind/l corresponding to the lowest density in our study provides good survival and resulted in the best growth of *O. niloticus* fry. Among the different feeding rates tested, 15% of the total biomass corresponds to the best FCR, survival rate and growth rate of *O. niloticus* fry sexually inverted with 17*α* methyl hormone. Although the present study has improved our understanding of reproduction and larval rearing of *O. niloticus*, further analyses are needed to improve the growth fry performances, which are overall low compared to previous studies. This difference could be due to the intrinsic genetic potential of the studied strains. It would be interesting to conduct characterization, zootechnical performance and genetic selection studies on the different strains of *O. niloticus* present in Senegal. All the information, combined with the monitoring of water quality, can boost the local production of the species and lead to sustainable development of its farming in Senegal.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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