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Chapter

Nile Tilapia “*Oreochromis niloticus*” Farming in Fresh and Geothermal Waters in Tunisia: A Comparative Study

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Abstract

This work aims to compare the farming of Nile Tilapia *Oreochromis niloticus* in fresh and geothermal waters through monitoring the specie's zootechnical parameters: growth, mortality and feed conversion rate. For geothermal water rearing, fish was placed in cages in Bechima Station, in southern Tunisia, while Smati Reservoir, in the center of the country was used for fresh water. The spawners were first adapted to geothermal waters in Bechima experimental station. Then, the broodstock phase lasted 60 days and allowed the obtainment of 1–2 g larvae. Fertility was important and varied between 451 and 1589 larvae/female, which is associated with the females' total weight ($F = 1.6 W^{2.1}$). In the pre-growing phase, the comparison of fry growth rates (weight 1.3 g) in the geothermal and freshwaters showed a small variation with recorded rates slightly in favor of fish bred in fresh water. During 50 days within the breeding phase, fish weight achieved in freshwater was more important reaching 12.7 g (TCJ = 0.228 g /day compared to 10.51 g (TCJ = 0.184 g/day) recorded in geothermal waters. Similarly, during the fattening phase, the weights gained after 30 days demonstrated better growth rates for tilapia cultured in freshwater (up to 60 g) in contrast to that bred in geothermal water (35–40 g).

Keywords: *Oreochromis niloticus*, farming, freshwater, geothermal waters, Tunisia

1. Introduction

Across the ages, Man has been harnessing water resources to suit his needs whether for power generation or for food, fishing and aquaculture. The first aquaculture tryouts started more than 4000 years ago in Egypt with the production of the famous fish: Tilapia [1]. Till to date, tilapia has remained an important food resource, in the family Cichlidae, with two species being predominantly cultivated: Mozambique Tilapia (*Oreochromis mosambicus*) and Nile Tilapia (*O. niloticus*), which alone

accounts for more than 1/5 of the total global aquaculture production; and 85% of tilapia production [1–4]. Nile tilapia, a species native to the Nile River, also inhabits the Niger, Volta, and Senegal River Basins [1, 5, 6]. Thanks to its suitability for aquaculture and given its quick adjustment to extreme and varied environments, its ease of reproduction in captivity and its wide ecological valence, this fish has been the subject of various breeding attempts and has been widely spread in all continents since the 1960s [7, 8].

Around the world, several methods have been used to breed tilapia, including extensive (mostly in ponds), semi-intensive, intensive and mostly hyper-intensive systems. These methods are characterized by the use of selected strains and a high-performance compound feed [4, 9]. Nile Tilapia is widely known for its adaptability to different farming systems linked to its spawning period which spreads over the whole year. Likewise, this species is known for its resistance to pathogens as well as its ability to withstand stressful environments and the different manipulations associated with aquaculture [10].

In addition to the afore-mentioned advantages, *O. niloticus* has an intriguing growth rate, unique when compared to other species of the cichlid family. On top of a good food conversion ratio associated with an excellent ability to accept artificial feed [11–13], its diet corresponds to the lowest levels of the food chain (phytoplankton, detritus...). All these attributes make the production costs of this species relatively moderate and adequate. In Tunisia, in addition to mullet, pikeperch and carp, the rearing of *O. niloticus* could prove to be an interesting future alternative for the partial replacement of the production of other freshwater fish, given its very remarkable biological characteristics in inland fish farming.

Tilapia was first introduced in 1966 in Kebilli Oases, where aquaculture is often connected with agricultural practices, taking advantage of the warm climate and the abundant geothermal water resources in southern Tunisia. However, despite the unerring documentation of Tilapia's survival and reproduction [14], it was not until 1999, that the idea of breeding this species was pursued. This took place after the experimental research station in geothermal pisciculture of Bechima in the governorate of Gabes was founded by the National Institute of Sciences and Technologies of the Sea (NISTS). Since then, several experiments have reported effective management and success of the different rearing cycles of this species, from spawning to grow-out [15]. In parallel, various acclimatization experiments of tilapia have been conducted in the southern oases, as well as in the reservoirs in the north and center of Tunisia, where the low winter temperature hinders the growth and survival of this species. These experiments have shown encouraging results and breeding success especially at the reservoirs of Lebna, Lahma, Ghezala and Sidi Saâd [16, 17].

The present study was commissioned by the Technical Center of Aquaculture (TCA) and the Higher Institute of Fishery and Aquaculture of Bizerte (HIFAB), within the framework of a convention signed in 2015 between the TCA and the NISTS which aims to ensure the annual production of 300,000 single-sex male Nile tilapia fry. In other respects, the researchers sought to identify the most suitable environment for the rearing of this species in Tunisia through pinpointing the strengths and weaknesses associated with this species' farming in two quite different environments (fresh and geothermal waters). To achieve this goal, the physicochemical parameters of the study areas, zootechnical parameters of the fish and pathologies were considered on top of the monitoring and evaluation of the different rearing phases (hatching, larval rearing, and grow-out) and the economic study.

2. General overview of the hydric and aquaculture potentials in Tunisia

2.1 Aquaculture in Tunisia

In Tunisia, according to the General Directorate of the Environment and Quality of Life [18], 5 types of aquatic livestock farming activities currently exist: marine fish farming, inland fish farming, fish farming in geothermal waters, shellfish farming and tuna grow-out. These aquaculture activities date back to the 1960s and they started with the rearing of sea bass *Disentrarchus labrax* and sea bream *Sparus aurata* in marine waters. At that time, the competent authorities set up a strategy for the exploitation of the dams' reservoirs as a significant hydro-ichthyic support. However, the first attempts to introduce freshwater species into the reservoirs have proven that only carp (*Cyprinus carpio communis*, *Cyprinus carpio specularis*, *C. carpio coriaceus*), roach (*Rutilus rubilio*) rudd (*Scardinius erythrophthalmus*), pikeperch (*Sander lucioperca*), black-bass (*Micropterus salmoides*), mullets (*Chelon ramada*, *Mugil cephalus*) and Nile Tilapia (*O. niloticus*) were able to acclimatize [14, 17, 19]. That said, inland fish farming in water reservoirs and hill lakes in Tunisia remains of paramount importance and contributes with 1000 tons/year in the total fishery production [20].

2.2 Water potential and aquaculture sector in Tunisia

According to the GDDLHW [21], the Tunisian water network extends over a total area estimated at 20,000 ha, retaining more than 4.2 billion m³ of water. This network consists mainly of dams, hill reservoirs and hill lakes generally located in the north and center of Tunisia. Eventually, the possibilities of development of the aquaculture sector are quite considerable. Indeed, Tunisia has significant natural potentials from north to south, distinguished by the presence of about 30 reservoirs and hill lakes, spread over 13 governorates between the north and center of the country. In addition, the south offers the opportunity to integrate fish farming with agriculture, where groundwater can efficiently contribute to the diversification and production of certain species in geothermal waters including Nile Tilapia. In fact, a great variety of hot water resources exists in southern Tunisia including the geothermal waters whose exploitable quantity is estimated at 737.8 Mm³/year [13]. This potential consists of deep resources mainly distributed among three aquifers: Intercalary Continental, terminal complex aquifers and Jefarra Basin [15]. This prospect helped initiate endeavors for both tilapia farming and agriculture. Indeed, the idea has converged towards the diversification of breeding species with respect to those introduced in the reservoirs (mullet, pike perch, catfish). Thus, a twofold exploitation and valorization of geothermal water has been achieved as the same water is used for both agriculture and fish farming enriching the agricultural areas with nutrients and fish organic elements [15]. However, the type, accessibility and quantity of the water available, can constitute significant limiting factors for the initiation of tilapia production in the south [16].

3. Overview on Tilapia production

3.1 World production

In 2015, Tilapia group ranked third in terms of production worldwide after Cyprinidae and Salmonidae. Global tilapia production has increased rapidly since the

1980s and reached 3,670,259 tons in 2014 [22]. This production is mainly destined to the U.S. market, the main importer of this fish. In terms of geographical location, Asia accounts for more than 80% of tilapia production in the world, with China as the largest producer with 1 M tons. On the other hand, while Africa is the native environment of tilapia, its production remains extremely limited (apart from Egypt and Zimbabwe) [22, 23].

3.2 Tilapia production in Tunisia

Nile tilapia (*O. niloticus*) was the first exotic species reared in Tunisian geothermal waters, particularly due to its rapid growth and tolerance to high temperatures. In addition, the remarkable adaptation of this species and the highly motivating results of its breeding have attracted the private sector to invest in this activity since 2009 in the governorate of Medenine [20]. However, the production of tilapia has remained low compared to other groups of freshwater fish (5428 Tons against 1,034,035 compared to the rest of the species). Most of this production is realized in the reservoirs of Lakhmés (Siliana), Lebna (Nabeul) and Sidi Saâd (Kairouan) [20]. The average market price is also low (3–4 TD/kg; which corresponds to 1.2–1.7 €) and remains uncompetitive compared to other farmed fish. The reason is that tilapia, like most freshwater fish, is not in the dietary habits of Tunisians and its market is quite small.

4. Presentation of the species *O. niloticus* (Linnaeus, 1758)

Like all tilapias, *O. niloticus* is a member of the family Cichlidae (**Figure 1**). The systematic position adopted for this species is the following [1, 9] Phylum: Vertebrates; Subphylum: Gnathostomes; Superclass: Fishes; Class: Osteichthyes; Subclass: Teleosts; Order: Perciformes; Suborder: Percoids; Family: Cichlidae; Subfamily: Tilapinae; Genus: *Oreochromis*; Species: *niloticus*.

4.1 Morphological characteristics of the species

Nile tilapia is a Cichlid belonging to the group of maternal mouth-brooder fish. It is characterized by a grayish coloration with pinkish breast and flanks, alternating light, black vertical stripes clearly visible especially on the caudal fin and the posterior part of the dorsal fin, a high number of long and thin gill rakers (18–28 on the lower part of the first gill arch and 4–7 on the upper part), a long dorsal fin with a spiny anterior



Figure 1.
Nile tilapia (present work).

part (17–18 spines) and a soft posterior part (12–14 rays), and a black border on the dorsal and caudal fin in males [24–26]. *Oreochromis niloticus* can be easily distinguished from any other species of tilapia that has more or less the same characteristics mentioned above, i.e., *O. aureus*, but which shows in males an additional red border along the edge of the dorsal and caudal fins [27, 28].

4.2 Ecological requirements

Thanks to its high adaptability to biotic and abiotic ecological factors, Tilapia rearing can be carried out in fresh and warm waters, as well as in well-controlled conditions after acclimation [17]. *O. niloticus* is a eurylecious species that adapts to large variations of ecological factors as it is able to adjust to extremely different environments [29, 30].

Table 1, below, summarizes the various average values of the physicochemical parameters that this fish tolerates for its survival.

4.2.1 Temperature

Temperature represents a main factor that conditions either way the properties of the water required for rearing and the different growth phases of tilapia. In natural environment, tilapia is a eurythermic fish that can withstand important temperature disparities [32]. Thus, it is possible to find this fish at temperatures ranging between 14 and 33°C. Within breeding conditions, the lower and upper lethal temperatures recorded are 7.4 and 40.73°C respectively [33, 34]. Above 16–17°C, the fish stops feeding and becomes increasingly susceptible to a series of diseases [35–38]. For reproduction, the appropriate temperature ranges between 22 and 30°C [39–41]. In Tunisia, the optimal average temperature for tilapia breeding is between 9 and 28°C in the reservoirs. Moreover, Derouiche et al. [17] reported that this species can adopt a hibernation strategy to survive and grow when the winter temperature is around 9°C (Lebna Reservoir). On the other hand, conducted experiments of the species farming in southern geothermal groundwater show a tolerance of 36 and 40°C [42, 43].

4.2.2 Salinity

Although most tilapia are freshwater species, their ability to adapt to different salinities is clearly remarkable [44, 45]. For example, *O. niloticus* can adjust to waters with salinity between 0.015 and 30 PSU [46]. Similarly, in Tunisian geothermal waters, tilapias show their ability to withstand high salinities up to 28 g/l [43]. However, with regard to reproduction, this fish would be unable to reproduce in a salinity that exceeds 15–18‰ [47, 48].

Parameter	T (°C)	Salinity (PSU)	Alkalinity (mg/L)	Hardness (mg/L)	Ammonia (mg/L)	Dissolved oxygen (mg/L)	pH
Interval	26–32	0–20	> 20	< 50	< 0.1	3–5	6.5–8.5

Table 1.
 Water quality requirements for Nile Tilapia culture [31].

4.2.3 Dissolved oxygen

Tilapia are capable of surviving in conditions where the dissolved oxygen concentration is very low [49]. Indeed, they can even withstand levels below 0.5 mg/l, which is considered to be below the threshold level tolerated by most aquaculture species [50, 51]. However, a minimum level of 2 to 3 mg/l is recommended in rearing, otherwise, a depression of the metabolic rate and growth can affect the production.

4.2.4 The hydrogen potential (pH)

Nile Tilapia presents a capacity of survival in environments of extreme pH. However, the optimal pH advised for its survival and its breeding oscillates between 7 and 8 [39, 45, 49].

4.2.5 Nitrogenous compounds

In fish farming, ammonia poisoning is closely related to pH. When this substance increases, it leads to the transformation of a significant amount of total ammonia into its toxic form (NH_3) [16, 52]. The concentration of nitrogenous metabolic waste excreted through the gills, urine depends mainly on the temperature, the size of the individuals, and the quantity and amount of food distributed. This concentration must be kept below the critical threshold of *O. niloticus*, not exceeding 5 mg/l for nitrate, 500 mg/l for nitrite, and 15 mg/l for total ammonia [53].

4.2.6 Photoperiod

The action of light, although closely related to temperature, acts on the species' growth via the endocrine system. Mélard [54] explain that an optimal photoperiod stimulates the secretion of growth hormone (GH) in *O. niloticus*. Moreover, larvae are more sensitive to photoperiod than fry and juveniles [48, 55]. Experimentally, larvae that are exposed to a long period of light (18-24 h) have a better growth and a significantly higher food efficiency than those exposed to a short or intermediate period between 6 and 12 h [55].

4.3 Reproductive biology

4.3.1 Reproductive behavior

In the wild, when abiotic conditions are appropriate, adults migrate to a shallow area with a loose substrate (gravel, sand, clay). After choosing the site for their own nest, each male aggressively defends its territory and digs a plate-shaped nest with its mouth. The females living in a school near the breeding grounds move between the males and each one tries to acquire a partner [15, 56].

4.3.2 Sexual maturity

The size of the first sexual maturity of *O. niloticus* varies between 14 and 20 cm. However, under stressful conditions, this species can reproduce as early as 3 months of age, at a weight of less than 50 g [57]. Moreover, the reproduction period of this species is exponentially continuous during the whole year when the water

temperature is higher than 22°C [52]. Thus, in Tunisia, the study conducted by Azaza et al. [58] on the reproduction of Nile tilapia in captivity in the geothermal waters in southern Tunisia, showed that this fish reaches its first sexual maturity during the first year of rearing, with an Lm50 equal to 11.3 cm for females and 12.3 cm for males.

4.3.3 Fertility

Absolute fecundity is defined as the number of eggs freshly recovered from the oral cavity of a female. In tilapia, as in other fish, this fecundity increases with the size of the females. As reported by Mélard [54], the minimum absolute observed fecundity for a 26 g female is 340 ovules and the maximum fecundity for a 550 g female is 3500 ovules. In addition, Dhraief et al. [8] proved that this parameter increases with the length of the females. On the other hand, Mélard [54] demonstrated that relative fecundity (expressed as the number of fertilized eggs or fry produced/kg of female) varies inversely with the average weight of tilapia females.

4.4 Growth

It is commonly accepted that Fish have a predetermined typical growing course dependent on genetic factors which interact with other environmental aspects. Thus, the growth rate is extremely alterable depending on the controlling factors, such as temperature and limiting factors including food, oxygen, and ammonia which affect the amount of energy available for growth. Similarly, other secondary factors such as stocking density and photoperiod, can certainly affect the growth of the species [59]. Moreover, in *O. niloticus* there is a phenomenon of sexual dimorphism of growth which appears very quickly in rearing: the males have better growth performances than females, due to the particularity of the reproductive process in females (oral incubation) and social behavior (territoriality, etc.) [24].

4.5 Production of single-sex male population

In order to optimize *O. niloticus* production systems, rearing of single-sex male populations is sought more and more in tilapia farming for many reasons. First, males grow twice as fast as females [35, 60]. Another reason is to avoid reproduction which would result in an overpopulation of small individuals in the rearing environment [61], and eventually ensure a homogeneous population at the time of harvest, with an interesting individual size and good commercial value.

4.6 Pathological risks

Like all aquatic species, Nile tilapia can be prone to a range of diseases resulting from the proliferation of certain pathogenic organisms. Generally, bacteriological diseases remain the most prevalent, namely Mobile *Aeromonas septicemia* and *Vibriosis*, resulting primarily from stress and poor water quality. Affected fish show signs of burns on the skin and fins and a loss of balance associated with abnormal behavior [9, 52]. Results obtained from a study done in tilapia farms in Ghana, revealed three types of ectoparasites: *Trichodina sp.*, *Monogenes* and *Tetrahymena sp.*, of which the first two were common in most farms, but did not pose real problems.

4.7 Diet

In the wild, tilapia is an omnivorous fish. In aquaculture, however, it shows an ability to consume various products, co-products and waste products that are considered valuable, such as palm nuts, soybean or cotton cakes, rice flour, rapeseed, alfalfa and animal excrements [51, 62]. In Tunisia, a study conducted on the development of dry feeds for *O. niloticus* by Derouiche *et al.* [17] showed that the best growth and feed conversion rates were obtained by feeds containing 20% and 30% of fish meal, with conversion rates of 1.71 and 1.49.

5. Materials and methods

5.1 Presentation of the study areas and breeding structures

The aim of this work is to identify the most suitable environment for the rearing of *O. niloticus* in Tunisia. To achieve this goal, this study was held investigating two areas with different types of waters: the experimental station of Bechima (geothermal water) and Smati Reservoir (fresh water). In addition to the main infrastructure intended for the preparation of broodstock for reproduction, spawning and the production of larvae, the production of juveniles and young individuals requires appropriate infrastructure, such as cages and enclosures which are efficient and resistant to environmental factors.

5.1.1 Bechima experimental station

Bechima experimental station is a research unit created in 1999 by the NISTS in Al-Hamma region in the governorate of Gabes in southern Tunisia. It is located in the vicinity of a cooler on a slope of 3% to ensure a continuous circulation of water by simple gravity. Two artesian wells supply the station with geothermal water at a temperature of 70°C. This water is cooled by the atmosphere to reach an average temperature of about 30–40°C. In terms of infrastructure, the station is equipped with 3 greenhouses containing breeding, larval rearing, hatching and rearing tanks [15].

5.1.2 Smati reservoir

Smati Reservoir covers an area of 121 km² and is located in the region of Al-Ala in the governorate of Kairouan, central Tunisia on Smati Wadi. The average salinity and depth are estimated at 2.3 PSU and 1.5–2 m respectively. In addition, according to the General Directorate of Fisheries and Aquaculture [20], this reservoir offers ichthyic habitat for two species namely the mullet *M. cephalus* and the Barbel *Barbus callensis*, with a total production estimated at 17.3 tons in 2015.

5.1.3 Design and assembly of breeding structures

In order to facilitate handling and transport and to minimize costs, the used cages and enclosures were built with respective volumes of 3 m³ (with Length = 1.5 m, Width = 1.3 m and Height = 1.5 m), and 2 m³ (with Length = 1.3 m, Width = 1 m and Height = 1.5 m), using a mesh size of 6 mm of polyamide nets. In total, 31 cages were constructed, of which only five were initially installed in the large tank for the phases

of pre-growing and grow-out in Bechima Station. In addition, six enclosures were built for the rearing of individuals in a semi-extensive system in Smati Reservoir, of which two were used for hatching and two others for rearing at a depth of 1.5-2 m [63].

5.2 Biological material and breeding procedure

5.2.1 Biological materials

O. niloticus, in particular the strain "Maryout", subject of this zootechnical study was introduced in 1999 from Libya within the framework of research cooperation between the NISTS and the Marine Science Center of Tajoura [64].

The experiments started with the collection of more than 6000 larvae (average weight = 0.01 g) from 13 broodstock (weight between 99 and 190 g) which were well adapted to life in captivity in the geothermal waters of Bechima. These larvae were subdivided into 2 batches, to be prepared for an initial pre-growing phase of 60 days in two larval tanks, located in the larval rearing greenhouse of the station, with the aim to obtain fry of 1 to 2 g. The latter were then transferred to two cages and two enclosures which were installed respectively in Bechima Basin and in Smati Reservoir in order to obtain juveniles of 15–20 g (50 days). Finally, a sorting was ensured based on average weight and sex to produce neo males and to start the last phase of production: the grow-out.

5.2.2 Breeding procedure

5.2.2.1 Collection of eggs and larvae

During this study, the broodstocks were maintained under optimal abiotic rearing conditions. In fact, several signs allow the identification of incubating females, such as the appearance of a dark band on the forehead and black spots on the flanks, as well as a fast and discontinuous swimming with a rather aggressive behavior towards other specimens in the tank.

5.2.2.2 Females reproductive parameters

Once the female identified and isolated, they are weighed and measured. This procedure allows the evaluation of two important parameters: relative and absolute fecundity, which describe the productivity of the females per day according to weight and length. The absolute fecundity refers to the total number of eggs present in a female before fertilization. Relative productivity represents the total number of larvae produced per day in relation to the total biomass of females in g.

5.2.2.3 The broodstock phase

Larvae were obtained by spitting technique. The handling of the larvae as a count is a delicate operation, requiring a particular follow-up not to stress the unhatched eggs and larvae. The latter were reared for 60 days in cubic tanks with a unit volume of 1m³, a density of 800 larvae/m³, and a flow rate of 4 to 6 l/min. As for nutrition, larvae were fed 40% of protein levels in order to obtain fry with an average weight of 1 to 2 g.

5.2.2.4 *The breeding phase*

The breeding/pre-growing phase started on May 11th, 2017, in the floating cages installed in the rearing tank at Bechima experimental station (average weight: 1 to 2.03 g). One day later, 3009 larvae (average weight of 1.35 g) were transferred to the enclosures. At the end of this phase, a sexual sorting of the fry was required to start the rearing of the mono-sex populations. The density adopted for each structure is 500 individuals/m³. Moreover, beyond a size of 20 g, sexual dimorphism can be observed and the distinction between males and females is possible. Indeed, in males, the genital papilla is protuberant in the shape of a cone and carries a urogenital pore at the end. On the other hand, in females, it is small and round, found in the middle of a transverse slit (oviduct) which is located between the anus and the urethral orifice (urinary pore) located at the end.

5.2.2.5 *The fattening phase*

From mid-July onwards, we started the fattening/grow-out phase of the reared fry. In general, the sorting was first based on size that allowed the retainment of individuals with an average weight greater than or equal to 20 g. Towards the end of August, males and females were reared separately to later evaluate growth rates for both sexes. Regarding nutrition, the supplemented food for tilapia was the same in both environments with 30% of protein level and was distributed at a rate of 10% on a daily basis.

5.2.2.6 *Watching out for pathology*

In order to ensure the success of the different rearing stages, a certain level of cleanliness and hygiene in the experimental tanks had to be maintained on a daily basis. The bottom was siphoned off before feeding, in order to eliminate feces and any kind of deposit of food, thus avoiding the development of pathogenic organisms. In addition, specific measures related to the health of the group, were taken while monitoring the condition of individuals and their behavior.

5.2.3 *Nutrition*

The added food was composed of raw materials available on local market and prepared in Bechima pilot station, with variable proportions according to the fish stage development and following the formulas provided by the research of the NISTS (**Table 2**).

Ingredient (%)	Broodstock	Larvae	Fry	Adults
Soybean cake	41	45	50	43
Fishmeal	14	25	20	14
Corn	35	20	20	935
Vegetable oil	8	8	8	6
VMS	2	2	2	2

Table 2.
Composition of tilapia food according to rearing phases [13].

This food is rich in protein with a level up to 40%. In addition, vitamins and minerals from the Mineral Vitamin Supplement (MVC) were provided in the food to meet the dietary requirements of the species. The rationing rate, the granulometry and the quantity of the food supplied vary according to the development stages, size and age of the individuals, the energetic value of the food and the variation of the physicochemical properties. The adopted rationing rate ranges from 20 to 10% (from the first day until pre-growth). The amount of food for broodstock (Qg) and for larval rearing (Ql) was determined in accordance with the following formulas:

$$Qg = (Nm * Mm + Nf * Mf) * TC \quad (1)$$

$$Ql = (Bf - Bi) * TC \quad (2)$$

With: Nm and Nf: numbers of male and female spawners; Mm and Mf: average weights of male and female spawners; TC: conversion rate; Bf and Bi: final and initial biomass during the larval stage.

Additionally, the remaining, not ingested, amount of food was monitored and estimated in order to fully adjust the supplemented amount to the needs of the fish.

5.2.4 Zootechnical parameters

To estimate the growth of fish during the different rearing phases, a number of indices and zootechnical parameters should be calculated.

5.2.4.1 Body weight gain

This index is used to evaluate the weight growth of fish during a given time. It is calculated according to the following formula:

$$\text{Gain in average weight (g)} = \text{final weight (g)} - \text{initial weight (g)} \quad (3)$$

5.2.4.2 Daily growth rate (DGR)

This parameter is determined for a short period of time from a fish sample during all rearing phases and is estimated according to the formula:

$$DGR = \frac{\text{Final Mass} - \text{Initial Mass}}{\text{Time}} * 100 \quad (4)$$

5.2.4.3 Mortality

This zootechnical parameter is of crucial importance when evaluating the rearing performance. It is therefore vital to monitor the cumulative mortality rate in the larval, fry and juvenile fish stock. This is the ratio of the number of dead individuals to the total population during a given timespan.

$$\text{Mortality rate} = \left(\frac{\text{Number of dead organisms}}{\text{Total Nomb}} \right) * 100 \quad (5)$$

5.2.4.4 Survival rate

The survival rate is well correlated to the mortality rate. It is calculated from the total number of fish at the end of the experiment and the number of fish at the beginning of the rearing, according to the following relationship:

$$\text{Survival Rate} = \left(\frac{\text{Final specimens number}}{\text{Initial specimens number}} \right) * 100 \quad (6)$$

5.2.4.5 Food conversion rate (FCR)

It is a food conversion index that measures the efficiency of the transformation of nutrition into fish flesh. It represents the ratio between the total amount of the supplied food to the fish and the gain obtained in fish weight.

$$\text{FCR} = \frac{\text{Dry weight of the supplied food}}{\text{Gain in fish weight}} \quad (7)$$

5.2.4.6 Daily feeding ration (DFR)

It is the ration supplied per day of rearing, and it depends closely on the feeding rate.

$$\text{DFR} = ((\text{Average weight} * \text{Feeding rate}) / 100) * \text{Nombr of larvae} \quad (8)$$

5.2.4.7 Length-weight relationship

In order to properly control the growth parameters of broodstock, pre-grown fry and grown individuals in both environments, it is necessary to establish the relationship between the size and weight of the fish, which is defined according to Le Cren [65] by the following equation:

$$W = aL^b \quad (9)$$

with W: the weight of the fish in grams; L: the length of the fish (TL, FL or SL) in centimeters; a: slope; b: coefficient of allometry defined as the coefficient of relative growth in weight.

Three cases can be distinguished: if $b = b$ theoretical, there is an isometric allometry between the two characters, if $b < b$ theoretical there is a negative allometry, and if $b > b$ theoretical, the allometry is positive [66].

5.2.5 Monitoring of physico-chemical parameters

Throughout the whole experiment and during all the rearing phases, monitoring the physicochemical parameters was of primary concern. The different parameters, notably temperature, salinity, pH, and dissolved oxygen were measured with a Multi 350i/SET. Nitrites, nitrates and ammonium were also kept track of, because of their impact on water quality. The various physicochemical analyses were made in situ and in the laboratory.

5.2.6 Data analyses

The study of growth is a very delicate approach in fisheries and it requires a method which best suits the basic data, and the choice of the model that effectively describes the relationship between the variables. For this reason, and in order to have solid understanding of the prior effects of physicochemical and zootechnical parameters on the success of the rearing, it is necessary to carry out some statistical tests based on R, in order to determine the most suitable environment for tilapia farming. Thus, tests were conducted to determine the effect of different physicochemical parameters on larval rearing, pre-growth and grow-out.

6. Results and discussion

6.1 Evaluation of the rearing parameters of *O. niloticus*

6.1.1 Evaluation of broodstock fecundity

In this study, broodstocks were maintained under optimal abiotic conditions, thus 13 females ranging in size from 99 to 183 g were collected in the post-spawning phase. We established relationships linking the number of larvae obtained to the size and females body weight in order to study the absolute fecundity. In addition, the data were fitted with power curves, whose equation is $y = aX^b$.

The absolute fecundity observed during the first cycle varied between 451 and 1598 larvae/female (L/F), for respective weights of 113.4 and 183 g. However, the calculated average fecundity (806 L/F) was highly significant compared to research made by NISTS (600 L/F) and TCA (510 L/F) [30, 67]. The study of different parameters that can have a direct effect on fertility allowed us to establish the following relationships: height/weight, height/fertility and weight/fertility.

The analysis between the studied parameters shows a strong correlation between the size or total weight and the number of larvae produced by a female ($R^2 = 0.6$ and 0.645) (**Figure 2**).

The relationship between total tilapia broodstock weight and total length can be expressed as follows: $Pt = 0.0324 Lt^{2.7504}$ ($R^2 = 0.88$) (**Figure 3**).

With regard to the allometry coefficient, for all the broodstock exploited during the first rearing phase, it was below 3 ($b = 2.75 < 3$) indicating that allometry is negative for this species. This result affirms that *O. niloticus* gains in length more than it does in weight. Our results are concordant with those found by Coulibaly [68] at Lake Volta in Burkina Faso, but different from those obtained by Derouiche *et al.* [17] at Lebna Tunisian Reservoir (isometric allometry), and Du Feu [69] at Lake Kainji in Nigeria (positive allometry).

Mélard [54] observed variability in fecundity for the same size. The fecundity increases significantly as a consequence of the length of the females. These findings are similar to other results achieved by authors who studied Nile tilapia in Tunisia and demonstrated that b oscillates around 1.96 [8]. Despite the small size range in our sample (between 18.8 and 23.5), it was shown that absolute fecundity evolves proportionally with size, which is congruent with results obtained by other authors [15, 54, 70]. Generally, this is largely attributed to a genetic difference, and a possible complex interaction between fecundity, egg size obtained and the staggered periodicity of egg laying.

In contrast, for the same size range, fecundity was much lower in the *Oreochromis niloticus* buccal incubator compared to substrate-laying tilapia. These species fecundity

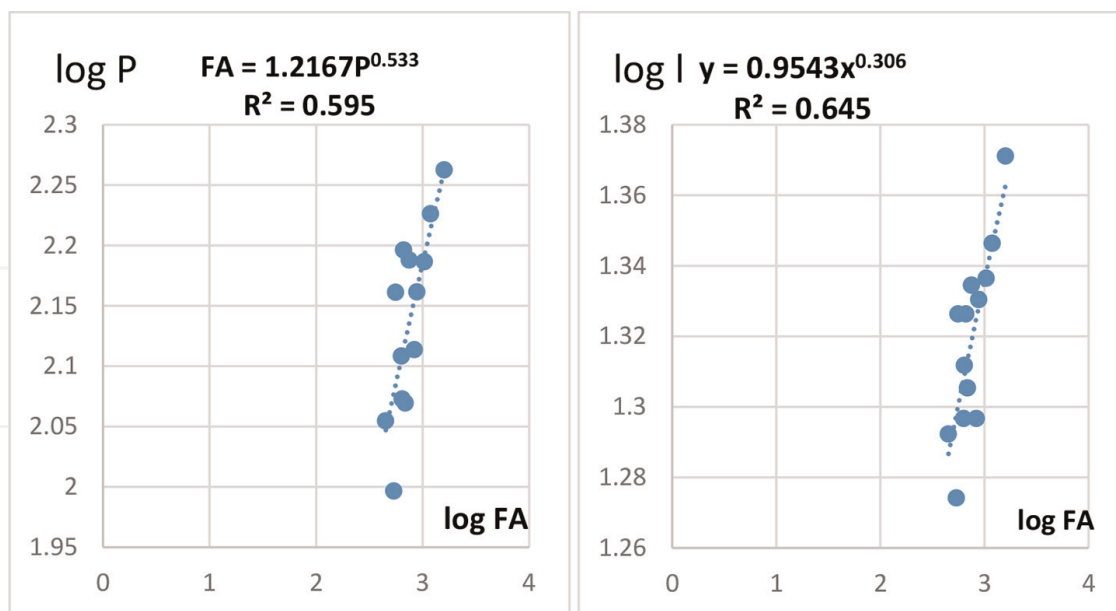


Figure 2.
Relative growth and fecundity curves for *Oreochromis niloticus* broodstock.

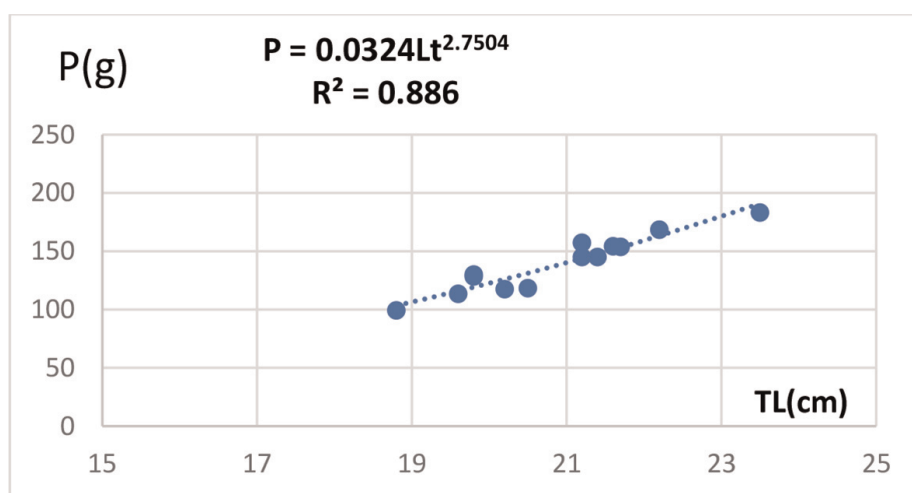


Figure 3.
Growth curve of female *Tilapia*.

ranged from 2314 to 5178 eggs in *Tilapia zillii* [72]. On the other hand, the results obtained on absolute and relative productivity are in close agreement with the research results achieved by Dhraief et al. [8]. In addition, the estimated relative productivity, which evolves significantly as a function of total female weight (2.43 to 10.08 larvae/g female), remains significant compared to that found in 2015 by TCA [30] (between 0.5 and 4.02) and Dhraief et al. [8] and which ranges between 1.4 and 6.8 larvae/g female.

6.1.2 Growth during broodstock phase

6.1.2.1 Evaluation of zootechnical parameters

Monitoring the evolution of the average weight of larvae, from the first phase, for 60 days allowed an estimation of pre-growth rates. A total of 6138 *O. niloticus* larvae, with an average weight of 0.01 g, were collected from 13 broodstocks on April 5th,

2017. After 36 days, all the 0.2–0.4 g larvae were distributed to two tanks with a volume of 1m³. The average weight of the larvae in the first batch increased from 0.4 g (initial weight: day of collection) to 2.55 g at the end of the experiment, which corresponds to a growth rate of 0.059 g/day. For the second batch, the larvae monitoring showed a growth rate about 0.023 g/day. This rate is considerably lower than that of batch 1 whose average weight evolved from 0.01 g to 0.85 g. The evolution of the larvae weight from the first phase of rearing which lasted 60 days allowed to estimate the growth rates. These are shown in **Figure 4**.

During this period, larvae were fed manually at a rate of 2 to 3 meals per day with ground powdered food consisting of fish meal, soybean, corn, vegetable oil and a mineral-vitamin complex. The product is fed slightly in excess with a feeding rate of 20% of the total larval biomass. The initial daily intake is 7 g of food/day. Regarding the mortality, we noted that at the end of the larval rearing cycle, the survival rate was about 70%. This rate is comparable with that obtained by the NISTS (in geothermal waters) and the TCA (in fresh waters). **Table 3** summarizes the different parameters, estimated during the larval rearing phase, obtained in previous studies.

Towards the end of larval rearing, the average recorded weight of larvae ranged from 0.85 to 2.55 g between the tail and head in the batches, respectively. Our results are slightly above the individual weights estimated by NISTS and TCA [30, 67].

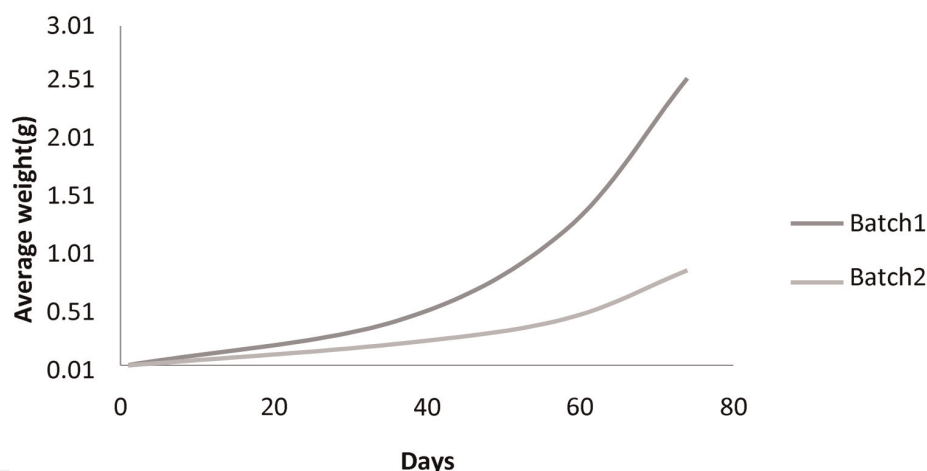


Figure 4.
 Evolution of the average weight of Nile Tilapia larvae.

Breeding parameters	Bechima (Present work)	Boumhel station (CTA) [30]	INSTM [67]
Survival rate (%)	70	49.64	68–84
Duration of breeding (days)	60	40	30
Average initial weight (g)	0.01	0,012	0.012
Average final weight(g)	0.85–2.55	0.73–2.12	2.5
FCR	2.25–2.51	1.32	1.97
Average temperature	28	27	30

Table 3.
 Comparative zootechnical parameters during larval rearing in *Oreochromis niloticus*.

The conversion index obtained in this study is 2.25 and 2.51 for batches 1 and 2 respectively. These values are higher than those attained by Philippart et al. [72] (IC = 1.1), TCA in 2015 (CI = 1.32) [30] and NISTS in 2009 (IC = 1.97) [67].

The comparison of our results with those achieved by other authors shows poor growth performance at the larval stage especially with the weight larvae heterogeneity (0.02-5 g) (size: 0.8-7 cm). This poor growth is firstly due to the: Quality and physiological state of the spawners; Egg and larval quality; Alterations during the manual counting of the larvae and during the cleaning operations of the larval rearing tanks (siphoning); Disturbance of water quality especially during the night and at dawn when oxygen is lacking; Quality of the dry food produced in the station; Low frequency of food distribution during the day (2–3 times/day), which seems to be lower than recommended (up to 8 times/day); Cannibalism phenomenon (this prompted us to make regular sorting, based on size, by separating the larvae into two batches); and High density of larvae placed in the larval rearing tanks.

6.1.2.2 Evaluation of water physicochemical parameters

The physicochemical parameters recorded in the two larval rearing tanks are relatively similar. The figure below (**Figure 5**) shows the variation of these parameters during 24 hours.

During larval rearing, the recorded temperature varied between 27.5 and 30.38 (average 28.84) during May and June 2017, respectively. To highlight the prior effect of abiotic factors on larval growth during larval rearing, statistical tests performed showed that temperature, followed by dissolved oxygen, control largely larval growth. We reported a decrease in oxygen level during the first hours of the day, which led us to install 1.5 hp. aerators to improve the performance of this parameter. On the other hand, salinity and pH seem to have a non-significant effect on larval growth.

6.1.3 Monitoring tilapia growth during rearing phase

6.1.3.1 Zootechnical parameters

As previously indicated, the fry obtained after 60 days of larval rearing was transferred to the two study areas, where the rearing and grow-out phases were initiated. The zootechnical parameters obtained in the pre-grown fry in the cages

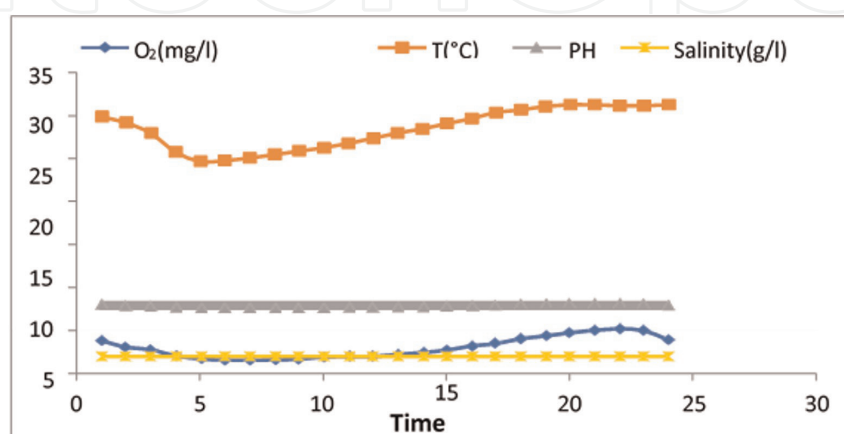


Figure 5. Average evolution of the water physicochemical parameters.

Zootechnical parameters of breeding	Geothermal water	Fresh water
Rearing time (days)	50	50
Initial staffing	3000	3000
Final headcount	1803	1761
Mortality rate (%)	39.9	41.3
Survival rate (%)	60.1	58.7
Initial weight average (g)	1.52	1.3
Final weight average (g)	10.51	12.7
Initial biomass (g)	4545	3900
Final biomass (g)	18949.53	22364.7
Amount of supplied food (g)	25,196	24,403
Daily growth rate (g/day)	0.179	0.224
Specific growth rate (%/day)	5.98	7.13
Feed conversion ratio (FCR)	1.36	1.05

Table 4.
 Zootechnical performances recorded in pre-grown tilapia in fresh and geothermal waters.

placed in the large rearing pond in Bechima Station (geothermal water) and the enclosures set in Smati Reservoir (freshwater) are reported in **Table 4**.

Growth performance expressed by the daily growth rate, the survival rate, and the conversion rate are in favor of the fish reared in the freshwater reservoir. Indeed, the growth rates recorded after 50 days of rearing are around 10.51 and 12.7 respectively for fish in geothermal water and in fresh water. Similarly, the conversion rates are of the order of 1.36 for fry reared in geothermal water and 1.05 for those reared in fresh water. For the fry length-weight relationship, we recorded a variation in *O. niloticus* growth. **Table 5** summarizes the different results obtained as well as the type of allometry.

In the freshwater pens we found that the relationship between total weight of *O. niloticus* fry and total length can be expressed as follows $P_t = 0.0096L_t^{3.1041}$ (n = 41,

Month	Zone	Slope comparison tests			Position comparison tests			Allometry
		Tpe	(+/-)	Interpretation	Tpo	(+/-)	Interpretation	
May	ED	0.87	–	equivalents	0.235	–	Confounded	–
	EG	0.95	–	equivalents	0.89	–	Confounded	–
June	ED	1.42	–	equivalents	1.014	–	Confounded	–
	EG	1.07	–	equivalents	0.973	–	Confounded	–
July	ED	1.66	–	equivalents	1.20	–	Confounded	+
	EG	1.43	–	equivalents	1.031	–	Confounded	+

Table 5.
 Tests of slopes and allometry positions of the weight-total length relationship per month in fresh and geothermal waters. (FW: fresh water; GW: geothermal water).

$R^2 = 0.6962$). On the other hand, it is expressed as $Pt = 0.0075Lt^{3.256}$ for cages placed in geothermal water. Moreover, the allometry coefficient is greater than three for the fry raised in both areas. Thus, this species exhibits a positive allometry between total weight and size. This asserts that this fish gains in weight more than in length. This result is congruent with the findings achieved at Lake Kainji in Nigeria [69] but it differs from the results found by Coulibaly [68] at Lake Volta in Burkina Faso (Minority allometry) and Derouiche et al. [17] in Lebna Reservoir (isometric allometry).

The monthly analysis of growth performance shows a slight difference in growth between the two zones over the study period. The value of the t-test is inferior to 1.96 at the 5% threshold. The month of July is characterized by a positive allometry in the reservoir and in Bechima station where the individual weight grows faster than the length.

Comparing the results of zootechnical performance between geothermal and fresh waters, it can be noted that the growth of pre-grown fry in pens at Smati Reservoir is superior to the fry raised in cages at Bechima fish farm. This may be due to the water quality at the rearing pond where the turnover rate is low. This is caused by the low flow of used water to maintain the temperature around 28–30°C. On the other hand, the water in Smati Reservoir seems to have physico-chemical parameters that are favorable to rearing.

Comparing our results with other studies, we note that at the Blonbey fish farm, fry of 1660 mg stocked in ponds at a density of 500 ind/m³ reach an average weight of 5980 mg. The daily growth rate is 210 mg/day, while the specific growth rate is about 5.98% per day. Our results are consistent with those found by Azaza *et al.* [58]. These authors indicate that they were able to achieve a daily weight gain of 0.4666 g/day during 15 days of hatching from fry of 2 g to an average weight of 9 g. The rearing adopted by these authors was conducted on a feed with the same composition as used in our experiment.

On the other hand, FAO states that a good daily growth rate can be obtained during 30 days and under intensive conditions (0.5 g/d daily gain) [73]. In Côte d'Ivoire, conducted hatching experiments have shown that growth rates are much better in 1m³ cages with a density of 1500 fry/m³. These experiments produced a fry weight of 25 g during 1 month with an estimated daily growth rate of 0.22 g.

The results from the pen rearing in Smati Reservoir are similar to those achieved by Azaza et al. [58] who obtained a daily growth rate of 0.43 g/day during 45 days. However, our results differ from those found by Lazard and Legendre [59] who got an average individual weight of 5 g after 2 months of pond rearing. This experiment was based on a dry feed composed of 20% of fishmeal, for fry with an average weight of 0.9 g, which corresponds to a daily weight gain equal to 68.33 mg/day. On the other hand, the good zootechnical performance observed during our experiment in fry pre-grown in fresh and geothermal waters is comparable to that of *H. longifilis* pre-grown made during 4 weeks in 4 m² tanks and whose average weight evolved from 4.5 g to 50 g [74].

6.1.3.2 Evaluation of physicochemical parameters during pre-growth phase

Tilapia farming is relatively difficult because it depends on the environmental factors of the water used. Indeed, the good management of a better water quality is the key to produce fry and fish in good conditions. The average values of the physicochemical parameters recorded at the two sites during the pre-growth phase are shown in **Table 6**.

Period	05/2017		06/2017		07/2017	
	Cages EG	Enclosure ED	Cages EG	Enclosure ED	Cages EG	Enclosure ED
Temperature	27	25.85	27.5	24.55	35.2	28.5
Salinity (g/l)	2	0.15	2.1	0.25	2	0.2
Dissolved Oxygen	6.78	8.875	8.38	5.755	9.7	6.21
PH	8.29	7.635	8.4	7.24	8	7.32
Average weight(g)	1.3	1.51	5.17	8.2	10.5	12.7

Table 6.
 Evolution of physicochemical parameters in fresh and geothermal waters.

6.1.3.3 Temperature

During the pre-growth phase, the monitoring of physico-chemical parameters in the freshwater and the geothermal water areas show that the maximum temperature values were recorded in July. The average temperature recorded in Smati Reservoir is estimated at 26.3°C against 30°C at the level of Bechima station. Eer *et al.* [75] have shown that a temperature between 20 and 30 °C is optimal for fish farming.

6.1.3.4 PH

Monitoring this parameter is momentous in farm management since inadequate pH values can influence the physiological fish state and their growth. Furthermore, it can lead to fish mortality, especially during the early developmental stages [53]. Throughout our study, pH values in the larval tanks, cages and pens showed small variations through time, but were still within the optimal tolerance range of the species (6.5–8.5) [53]. The average pH values recorded in the cages and pens are close and show a basic character of the rearing water (7.3–8.23). This species is tolerance to pH variations and it is found in waters with pH values ranging from 5 to 11; the ideal being located between 6.5 and 8.5 [53].

6.1.3.5 Dissolved oxygen

The dissolved oxygen levels measured in the two areas are within the scale of values recommended for fish farming [50]. The average oxygen level recorded varies between 6.94 and 8.28 mg/l in fresh water and geothermal water.

6.1.3.6 Salinity

Salinity monitoring showed that this parameter was almost constant during the 3 months of the experiment in both study sites. The values recorded are 2.03 g/l and 0.2 g/l respectively in the geothermal water and freshwater.

The analysis of the evolution of the physico-chemical parameters in the two areas showed that the values are well within the ranges recommended for Nile Tilapia farming. Indeed, this species is found in natural environment between 13.5–33°C [47, 76] and does not feed below 15°C [53].

In addition, *O. niloticus* tolerates both high oxygen deficits and saturations. Thus, up to 3 mg/l of dissolved oxygen, this species does not present any particular metabolic

difficulty. However, below this value, respiratory stress occurs, although mortality only occurs after 6 hours of exposure to 3 mg/l. Nevertheless, this species can withstand low concentrations of dissolved oxygen for short periods. The optimum required is 5 mg/l [53].

6.1.3.7 Effect of water on tilapia growth

To test the prior effect of abiotic factors on the zootechnical performance of fish during the pre-growth phase, we established statistical tests based on general linear models (GLM), by means of quantitative variables. These tests allow the complex parametric relationships between response variable and explanatory variables to be modeled; as well as to look for the most parsimonious relationship including only the relevant variables (using the AIC selection criterion). In addition, they make it possible to test the effects of explanatory variables and their interactions.

We followed the effect of physicochemical water parameters on the evolution of the total biomass of tilapia. We found that only temperature and dissolved oxygen govern the growth of individuals reared in freshwater and geothermal waters alike. Besides, the predictive study allowed to retain the variables mentioned above, showing the lowest value of AIC.

6.1.4 Growth parameters of tilapia during the grow-out phase

6.1.4.1 Physicochemical parameters

The table below (**Table 7**) illustrates the average values recorded of the water physicochemical parameters during the fattening phase. The study made during the grow-out stage allowed us to point out a clear difference in temperature between the two study areas. For the other parameters (dissolved oxygen and pH) remained very close and did not show significant variations.

6.1.4.2 Nitrogenous elements during breeding phase

Nitrogen is an essential compound in living structures, depending on the degree of oxidation; it exists in three forms in water: nitrites (NO₂⁻), ammonium (NH₄⁺) and

Parameters of Study area	Temperature (°C)	Dissolved oxygen (mg/l)	Salinity (PSU)	PH
EG Bechima	33.2	7.9	2	8.25
ED Smati Reservoir	27.6	7.64	0.2	7.8

Table 7.
Variation of physicochemical parameters between Bechima Station and Smati reservoir.

Parameter Environment	Hatching				Grow-out			
	NO ₂ ⁻ (mg/l)	NH ₄ ⁺ (mg/l)	NO ₃ ⁻ (mg/l)	P (mg/l)	NO ₂ ⁻ (mg/l)	NH ₄ ⁺ (mg/l)	NO ₃ ⁻ (mg/l)	P (mg/l)
EG Bechima	0.05	0.27	1.4	0.11	0.07	2.13	1.19	0.32
ED Smati Reservoir	0.06	0.12	1.7	0.25	0.38	0.34	3.4	2.43

Table 8.
Evolution of nitrogenous elements for pre-growth and grow-out in the two environments.

nitrate (NO₃⁻). The latter must be well controlled throughout the rearing period due to their toxic nature. The results of these analyses on the quality of the rearing water are reported in the following table (**Table 8**).

During the pre-growth phase, the analyses obtained in the two study areas are within the recommended ranges for rearing *O. niloticus*. In fact, the concentration of nitrogenous waste excreted by the gills and urine depends on various factors, namely temperature, fish size, ammonia concentration in the environment and the quality of the feed which must be kept below the critical threshold for survival of *O. niloticus*. Concentrations should not exceed 15 mg/l nitrate, 2 mg/l nitrite, 0.95 mg/l ammonium ions and 0.3 mg/l orthophosphate in any case [53].

However, at the grow-out phase, we recorded an increase in nitrite, nitrate and orthophosphate levels (at the reservoir). A high concentration of ammonia may have altered the taste and odor of the water. This may be explained by the increase in temperature during the summer season, and the phytoplankton bloom at the reservoir impoundment caused by the discharge of agricultural wastes and nitrogenous products. However, the majority of the waters of Tunisian reservoirs are classified as eutrophic to hypertrophic. These values remain below those recorded in the reservoir of Bir M’chergua whose nitrate concentration is estimated at 16.9 mg/l [77].

6.1.4.3 Growth parameters of Tilapia during fattening phase

The grow-out phase started in mid-July, so the monitoring period was quite restricted (30 days), and the young individuals were fed 3 times a day. Therefore, we will base our results on the daily growth rate. The following table (**Table 9**) summarizes the different zootechnical parameters recorded after 1 month of rearing.

The comparison of the growth performances between fresh and geothermal waters has shown high potentialities in favor of fish placed in the reservoir. Indeed, after 30 days, the total masses obtained varied between 30 and 59 g respectively in geothermal water and fresh water. Moreover, the highest growth rate is recorded in the

Zootechnical parameters of breeding	Grow-out in geothermal water	Grow-out in fresh water
Rearing time (days)	30	30
Initial staffing	1801	1761
Final headcount	1780	1749
Mortality rate (%)	1.17	0.69
Survival rate (%)	98.83	99.31
Average of initial weight (g)	10.4	12.7
Average of final weight (g)	30	29–59
Initial biomass (g)	18730.4	22634.7
Final biomass (g)	53,400	69,960
Amount of feed distributed (g)	16389.1	24,654
Daily growth rate (g/day)	0.65	0.54–1.54
FCR	0.47	0.2

Table 9.
 Zootechnical parameters of tilapia grown in Bechima Station and Smati reservoir.

Study area	Storage density (ind/m ³)	Rearing time (days)	Initialize (g)	Finalize (g)	Daily growth rate
Sidi Saad Reservoir (Tunisia) [42]	75	75	20.42	169.62	1.98
Lahma Reservoir [77]	177	131	16.28	238	1.69
Ghezala Reservoir [29]	61	118	27.42	204.49	1.5
Tall Lake (Philippines) [78]	71–76	150–180	14–17	250–300	1.57
China [79]	100–150	120–150	>50	600–800	4.625–5.06
Southern United States [80]	50	112	30	250	1.96

Table 10.
Comparative growth performance of Nile Tilapia in different environments.

pens placed in Smati Reservoir (ICJ = 0.4–1.54 g/d) against 0.65 g/d in the cages of Bechima Station.

On the other hand, we recorded very important survival rates compared to those obtained by other authors. This shows that Tunisian fresh waters and geothermal waters allow the growth and survival of this species. However, we recommend the maintenance of favorable conditions for the growth and survival of individuals including fish sorting which must be conducted in the future into 3 enclosures and 3 cages in order to homogenize the stock.

To highlight the results found in this study, we compared them with other authors' findings (**Table 10**).

The results show that the growth values found during this study are slightly below those attained by other researchers. On the other hand, fish grown in freshwater show daily growth rates close to those estimated by other authors who have worked in Tunisian reservoirs. In China, reported growth rates are high due to the use of large fry at the beginning of the grow-out phase and the good quality of the supplemented feed.

7. Conclusion

The present work contributes to the literature on Nile Tilapia farming "*O. niloticus*" in fresh waters (using enclosures placed in Smati Reservoir) and in geothermal waters (deploying cages installed in the large basin of Bechima experimental station) in Tunisia. This study was made March and August 2017, a period with abiotic conditions which are optimal for the rearing of this species. Larval rearing monitoring in the nursery located at the level of the greenhouse in Bechima Station has shown that the earliest larval stages are much more vulnerable than the most advanced stages. This vulnerability can be explained by the physical and physiological weakness associated to the fragility of larvae during their early stages of development, as well as their sensitivity to the manipulations associated to the rearing procedure. The larvae used in this study were collected from 13 broodstock in March 2017. During the 60 days of larval rearing, the average final weight increased from 0.01 to 0.85–2.55 g, and the survival rate recorded (70%) was within the range of values found by other authors.

The analysis of the evolution of the physico-chemical parameters measured in situ (temperature, dissolved oxygen, salinity and pH) as well as nutrients (nitrates, nitrites, ammonium and orthophosphates) shows that the values are well within the range recommended for Nile Tilapia rearing.

The preliminary results of the breeding phase in cages placed in the grow-out basin in Bechima station and in pens set in Smati Reservoir are quite encouraging. The comparison of the results obtained in cages placed in geothermal waters and in pens placed in the reservoir, has demonstrated that the breeding of frays in fresh waters shows a much better growth performance than in geothermal waters. The conversion rate obtained in fry, with body weights ranging from 3 to 19 g, reared in pens (0.87) is lower than that obtained in cages (1.62 and 1.58). In the grow-out phase, the results obtained after 30 days show that the fish reared in freshwater maintain the best growth performance compared to that reared in geothermal water. The preliminary results of the grow-out phase in Smati Reservoir are very encouraging compared to those achieved in Bechima Station. This observation highlights the great potential of this species' breeding and seeding in Tunisian reservoirs. The mortalities recorded in the two study areas are essentially due to cannibalism associated with the heterogeneity of the sizes and masses of the reared fish.

The in-depth diagnosis of this activity as well as the global evaluation of the results reveal the presence of anomalies and problems that must be addressed for the next reproduction and larval rearing campaigns in order to better manage this process and improve the production in the hatchery.

The results obtained shows that this type of fish farming has significant production potential. However, it presents two problems that must be solved, namely the massive production of calibrated fry of *O. niloticus* and the elaboration of a quality feed to meet the nutritional needs of fish. Thus, important improvements remain to be made in feeding and nutrition in order to specify and determine the standards of manufacturing and distribution of fish feed. This would ensure increased production and economic profitability along with a better coverage of the feed requirements of tilapia taking into account the economic context and the locally available compounds.

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Conflict of interest

The author declares no conflict of interest.

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