Ciência e Agrotecnologia
SCIENCE AND AGROTECHNOLOGY

Ciência e Agrotecnologia, 46:e009422, 2022
http://dx.doi.org/10.1590/1413-7054202246009422

Animal Science and Veterinary
eISSN 1981-1829

Nile tilapia nursery feeding management in a biofloc system

Manejo alimentar em berçário de tilápia-do-Nilo em sistema de bioflocos

Bruno Corrêa da Silva[1*], Karolina Victória Rosa[2], Haluko Massago[2], Raphael de Leão Serafini[1], Felipe do Nascimento Vieira[2]

[1]Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina/EPAGRI, Centro de Desenvolvimento em Aquicultura e Pesca/CEDAP, Itajaí, SC, Brasil
[2]Universidade Federal de Santa Catarina/UFSC, Departamento de Aquicultura, Florianópolis, SC, Brasil
*Corresponding author: brunosilva@epagri.sc.gov.br
Received in July 15, 2022 and approved in October 5, 2022

ABSTRACT

Nile tilapia (*Oreochromis niloticus*) has an opportunistic omnivorous feeding behavior and studies have demonstrated the consumption of microorganisms by the species from bioflocs, especially in the early phases of life. One may thus assume that when reared in biofloc systems, there may be a reduction in the feeding rates in the Nile tilapia nursery system when compared to the ponds. This study evaluated the effects of different feeding management options in Nile tilapia nurseries in a biofloc system. A total of 700 fingerlings (2.37 ± 0.55 g) were stocked in 20 experimental units (100 L) and inoculated with mature biofloc for the evaluation of five different feeding management options. After 49 days, it was observed that the higher feed rates caused an increase in nitrogen compounds and solids in the water, worsening the feed conversion rate. Furthermore, the excess feed supplied to the tilapia in the biofloc caused a reduction in the utilization of protein nitrogen, an increase in the liver and visceral fat, in addition to an increase in the production of solids and consumption of alkalinizer by fish biomass. On the other hand, low feeding rates cause a decrease in the growth and uniformity of the tilapia juveniles. Taking the results into consideration, it is recommended to use the feed management option proposed in treatment TC (26% below the highest feed rate) in the tilapia nursery in the biofloc system.

Index terms: Feeding rate; *Oreochromis niloticus*; super-intensive system; zootechnical performance.

RESUMO

A tilápia-do-Nilo possui comportamento alimentar onívoro oportunista e estudos demonstram o consumo de microrganismos dos bioflocos pela espécie, principalmente nas primeiras fases de vida. Assim, imagina-se que quando criados em bioflocos, pode haver uma redução na necessidade das taxas de alimentação quando comparado ao de viveiro escavado. Este estudo avaliou os efeitos de diferentes manejos alimentares em viveiro de tilápia-do-Nilo (*Oreochromis niloticus*) em bioflocos. Setecentos alevinos (2,37 ± 0,55 g) foram estocados em 20 unidades experimentais (100 L), inoculados com bioflocos maduros, para avaliação de cinco diferentes manejos alimentares. Após 49 dias, observou-se que as maiores taxas de alimentação provocam aumento dos compostos nitrogenados e sólidos na água, levando ao aumento na taxa de conversão alimentar. Além disso, o excesso de ração fornecido à tilápia em bioflocos causou redução na utilização de nitrogênio proteico, aumento do fígado e gordura visceral, além de aumento na produção de sólidos e consumo de alcalinizante pela biomassa dos peixes. Por outro lado, taxas de alimentação muito baixas causam diminuição no crescimento e uniformidade dos juvenis de tilápia. Levando em consideração todos os demais resultados, recomenda-se no berçário de tilápias em sistema de bioflocos utilizar o manejo alimentar proposto no tratamento TC (26% abaixo da maior taxa de alimentação).

Termos para indexação: Taxa de alimentação; *Oreochromis niloticus*; sistema superintensivo; desempenho zootécnico.

INTRODUCTION

Biofloc technology (BFT) tackles both environmental and economic issues by protecting water resources and achieving high yields (Avnimelech, 2012). Intensive tilapia culture is considered a sustainable alternative as it allows for the production of significantly higher biomass compared to conventional flow-through systems, consuming less water, as well as limiting the release of effluents to surrounding environments (Jatobá; Borges; Silva, 2019).

Several studies on tilapia rearing with BFT have been carried out in recent years. Among nutrition studies, different protein levels have already been evaluated in the diet for fingerlings (Silva et al., 2018; Amany et al., 2019; Durigon et al., 2020; Hisano et al., 2020; Sgnaulin et al., 2020), as well as the inclusion of alternative ingredients in diets (Caldini et al., 2015; López-Elías et al., 2015; Prabu et al., 2017), feed deprivation (Correa et al., 2020), and feeding frequency (Hisano et al., 2021). However, very few studies have been performed to evaluate different feeding rates in the tilapia nursery phase.

Nile tilapia has an opportunistic omnivorous feeding behavior and studies demonstrate the consumption of microorganisms from the biofloc by the species, especially in the early stages of life (Alves et al., 2017; Bossier; Ekasari, 2017). One can therefore assume that when reared in bioflocs, there may be a reduction in feeding rates in the Nile tilapia nursery system when compared to ponds.

Low feeding rates can stimulate the use of bioflocs by juvenile tilapia as a food source, thereby controlling the amount of solids in the system and getting low feed conversion (Poli et al., 2019). However, a low feeding rate can also delay animal growth. On the other hand, a high feeding rate can impair water quality, affecting growth, in addition to causing physiological problems in the liver and blood of fish (Huang et al., 2015; Silva et al., 2020).

Recent studies evaluating different feeding rates of tilapia in biofloc systems have adopted different strategies. Silva et al. (2020) observed the feeding of juvenile tilapia with different feeding rates based on apparent satiety. However, restricted feed management generally results in a lower feed conversion rate than that achieved by ad libitum management, in addition to being more easily performed by fish farmers in practice (Oliveira et al., 2021). In this sense, Oliveira et al. (2021) evaluated different rates of fixed feedings in the tilapia nursery (3 to 40 g). However, the need to feed juvenile tilapia in relation to the body weight varies greatly during this phase (Silva et al., 2019).

This study, therefore, aimed to evaluate the effects of different feeding management options in the nursery of Nile tilapia reared with BFT on water quality, zootechnical, and body parameters.

MATERIAL AND METHODS

Male Nile tilapia fingerlings (*Oreochromis niloticus*) were used with a mean initial weight of 2.37±0.55 g. All the procedures were carried out as per the guidelines of the Ethics Committee on the Use of Animals and approved by CEUA n° 305/2019.

Experimental design

Different feeding management options in growing tilapia with BFT were evaluated using 20 experimental units (100 L) comprising an aeration system and individual heaters (200 W) with a thermostat (28 ±1°C). In total, 700 tilapia fingerlings (2.37 ±0.55 g) were randomly used in quadruplicate, with 35 fingerlings per unit (350 fish per m^3).

The feed, bought from the Guabi Nutrição e Saúde Animal (São Paulo, Brazil), was administered four times a day (8 am, 11 am, 2 pm, and 5 pm) and adjusted according to a weekly weighing, by sampling 70% of fish/tank. The feedings followed five different feeding management options (TA, TB, TC, TD and TE), as described in Table 1.

The experimental units were initially inoculated with 30% of matured bioflocs and completed with filtered water (50 µm) to obtain a final value of approximately 400 mg L^{-1} of solids. In each tank, 0.1 ppt of common salt (NaCl) was added to prevent nitrite toxicity.

The matrix tank used to inoculate the bioflocs in the experimental units had the following water parameters on the day of the transfer: temperature 28.5 °C, 6.65 mg L^{-1} dissolved oxygen (DO), pH 7.03, 0.17 mg $N\text{-}NH_{3,4}$ L^{-1}, 0.50 mg $N\text{-}NO_2$ L^{-1}, 21.3 mg $N\text{-}NO_3$ L^{-1}, 118 mg L^{-1} alkalinity, 220 mg L^{-1} hardness, 52 mL setteable solids (SS), and 1.340 mg L^{-1} total suspended solids (TSS).

Table 1: Feeding management options in a Nile tilapia nursery with biofloc.

Fish size (g)	Diet	Amount of daily feed (%FW)				
		TA	TB	TC	TD	TE
1 to 5	1.0 mm 45%CP	8.20	10.50	12.70	15.00	17.25
5 to 10	1.7 mm 36%CP	4.40	5.60	6.80	8.00	9.20
10 to 20	1.7 mm 36%CP	3.85	4.90	5.95	7.00	8.05
20 to 40	1.7 mm 36%CP	2.75	3.50	4.25	5.00	5.75

CP: Crude protein, FW: Fish weight.

Water quality management

Dissolved oxygen (DO) and temperature were measured daily (YSI, model Pro 20), 30 min after the first feeding. The pH (YSI, Professional Plus model), total ammonia nitrogen (TAN), nitrite, and alkalinity were analyzed twice a week. The nitrate and hardness were analyzed at the beginning (1st day), middle (27th day), and end of the experiment (48th day).

TAN, nitrite, and nitrate analyses were performed with a micro-processed photocolorimeter and a colorimetric kit (Alfakit®). Ammonia was determined using the indophenol colorimetric method (4500-NH3 F, APHA, 2012), nitrite using the diazonium colorimetric method (method 4500-NO_2-B; APHA, 2012), and nitrate using the brucine method (Fries; Getrost; Merck, 1977). Alkalinity and hardness were performed using the titration method with a colorimeter kit (Alfakit®), using the methodology described in APHA (2012).

During the experiment, the water loss due to evaporation from the BFT was replenished weekly, with no renewal. Sodium bicarbonate ($NaHCO_3$) was added to the water of the experimental units twice a day (8 am and 5 pm) to maintain alkalinity between 60 and 100 mg L^{-1} and pH between 7.0 and 7.5. The amount of sodium bicarbonate was calculated based on the percentage of feed offered daily (w/w) in proportions ranging from 12% to 24% of the daily feed intake. This proportion was adjusted according to the analysis of pH and alkalinity.

The consumption of alkalizing (sodium bicarbonate) and feed intake were monitored for each experimental unit and the information was calculated using Equations 1 and 2:

$$Relative\ alkalinizing\ consumption\,(\%) = 100 \times \left(\frac{Alkalinizing\ consumption\,(g)}{Feed\ intake\,(g)} \right) \quad (1)$$

$$Alkalizing\ by\ biomass\,(g\ kg^{-1}) = \frac{Alkalizing\ Consumption\,(g)}{(FB - IB)} \quad (2)$$

where FB is the final biomass (kg $tank^{-1}$) and IB is the initial biomass (kg·$tank^{-1}$).

Solid management

Setteable solids (SS) and total suspended solids (TSS) were monitored twice a week from all experimental units using Imhoff cone and APHA (2012) methodologies, respectively. Every time TSS exceeded 600 mg L^{-1}, solids were adjusted to return to the value of 600 mg L^{-1}. Solids were removed by the water filtration in bag filters (50 µm). The volume to be filtered was calculated using Equation 3:

$$Vf = Vt - \left(\frac{SSTd \times Vt}{SSTa} \right) \quad (3)$$

where Vf is the volume to be filtered (L), Vt is the tank volume (100 L), SSTd is the desired total solids (600 mg L^{-1}), and SSTa is the total solids analyzed (mg L^{-1}).

At the end of the experiment, the total solids produced by each experimental unit and the total solids produced per kg of fish were also calculated, using the Equations 4 and 5:

$$Solids\ produced\,(g\ tank^{-1}) = (SSTf \times Vt) - (SSTi \times Vt) + \sum_{i=0}^{n} (SSTr \times Vf)\, n \quad (4)$$

$$Solids\ produced\ by\ biomass\,(g\ kg^{-1}) = \frac{Solids\ produced\,(g\ tank^{-1})}{(FB - IB)} \quad (5)$$

Where SSTf is the final total solids (g L^{-1}), Vt is the tank volume (100 L), SSTi is the initial total solids (g L^{-1}), SSTr is the total solids on removal day (g L^{-1}), Vf is the filtered volume (L), FB is the final biomass (kg $tank^{-1}$), and IB is the initial biomass (kg $tank^{-1}$).

Zootechnical performance

All experimental units were harvested on the 49th day of rearing to obtain the following zootechnical parameters: specific growth rate (SGR), daily weight gain (DWG), feed conversion rate (FCR), yield, survival, and uniformity. For this, the following formulas were used (Equations 6, 7, 8, 9, 10 and 11):

$$SGR\,(\%) = 100 \times \left(\frac{ln(FW) - ln(IW)}{t} \right) \quad (6)$$

$$DWG\,(g\ day^{-1}) = \frac{(FW - IW)}{t} \quad (7)$$

$$FCR = \frac{FI}{(FB - IB)} \quad (8)$$

$$Yield\left(\frac{kg}{m^3} \right) = \frac{FB(kg)}{V(m^3)} \quad (9)$$

$$Survival\,(\%) = 100 \times \frac{Nf}{Ns} \quad (10)$$

$$Uniformity\,(\%) = 100 \times \frac{N \pm 20\%}{Nf} \quad (11)$$

Where FW is the final weight (g), IW is the initial weight (g), t is the rearing time (days), FI is feed intake (g), FB is final biomass (g), IB is initial biomass (g), V is the experimental unit volume (m3), Nf is the total number of fish harvested, Ns is the initial number of fish stocked, and N ±20% is the number of fish within ±20% of the average weight of the experimental units (Piedras et al., 2005).

Body assessments

At the beginning and end of the nursery phase, samples of approximately 100 g of fish were collected and frozen in a –20 °C freezer, in addition to samples of the diets used in the experiment. Dry matter and total nitrogen of these samples were subsequently quantified using the methodologies described by the (Association of Official Analytical Chemists – AOAC, 1999) dry matter was quantified by gravimetrically drying the samples until constant weight, and protein by the Kjeldahl method. It was thus possible to carry out the analysis of nitrogen retention and protein efficiency rate, using Equations 12 and 13:

$$Nitrogen\,retention(\%) = 100 \times \frac{(FB \times BNf) - (IB \times BNi)}{Total\,nitrogen\,intake} \quad (12)$$

$$Protein\ efficiency\ rate\,(PER) = \frac{Weight\ gain\,(g)}{Total\ protein\ intake\,(g)} \quad (13)$$

where FB is the final biomass, BNf is the % final body nitrogen, IB is the initial biomass, and BNi is the % initial body nitrogen.

At the end of the experiment, four animals were sampled per experimental unit to assess the hepatosomatic index (HIS) and percentage of visceral fat (VF) (Equations 14 and 15).

$$HSI = 100 \times \frac{Liver\,weight\,(g)}{Fish\,weight\,(g)} \quad (14)$$

$$VF = 100 \times \frac{Visceral\ fat\,weight\,(g)}{Fish\,weight\,(g)} \quad (15)$$

Data analysis

Data normality and homoscedasticity were determined using the Bartlett's and Shapiro-Wilk tests, respectively. The data were subsequently subjected to a one-way analysis of variance. Nitrite concentration data were transformed into log10 (x + 1). Separation of means was performed using Tukey's test. All statistical analyses were performed using R program (package version 4.1), with significance level of 5%.

RESULTS AND DISCUSSION

Water and solids analyses

Among the analyzed parameters, temperature and hardness were not altered with the different feeding management (Table 2). Temperature was maintained at optimal performance values for Nile tilapia (Silva et al., 2019). In terms of hardness values and the hardness: alkalinity ratio were within values that do not affect the zootechnical performance of tilapia juveniles, according to the literature (Cavalcante et al., 2012; 2014).

DO values were lower in the treatments with the higher feeding rates. However, values below 5 mg L^{-1} were observed only in the TE treatment (higher feed rate) in the last week of rearing. Increasing the feed rate in the tilapia nursery with BFT increased nitrogen compounds, as expected, due to the higher nitrogen input by the feed (Table 2). However, the values of TAN, nitrite, and nitrate were within adequate levels for Nile tilapia (Monsees et al., 2017; Silva et al., 2019). Nitrite mean values were above 1 mg N-NO_2 L^{-1}, primarily between treatments TC, TD, and TE, only after 30 days of rearing. Due to the use of slightly saline water, it is believed that the nitrite peaks presented in these treatments, with maximum values between 3.5 and 4.7 mg N-NO_2 L^{-1}, did not result in mortalities (Alvarenga et al., 2018). Although nitrate is less toxic than other nitrogenous compounds, values above 500 mg N-NO_3 L^{-1} are not recommended for tilapia in intensive systems (Monsees et al., 2017). During the experiment, only some of the replicates of treatments TD and TE showed nitrate levels above this value in the last week of rearing (Table 2).

The mean values of pH and alkalinity were also higher in treatments with higher feeding rates. However, the values were within the appropriate parameters for tilapia throughout the experiment (Silva et al., 2019). The highest pH and alkalinity values of the treatments with the highest feeding rate may be due to the alkalinizer management adopted in this study, related to the feed intake—the greater the amount of feed offered, the greater the amount of inorganic carbon (sodium bicarbonate) added to the system to neutralize the ammonia generated through the nitrification process. It was observed that the higher the feed rate, the lower the relative consumption of alkalizer, which ranged from 13.45% to 15.62% of the amount of feed offered. These values are similar to those reported by Martins et al. (2017, 2019), who used sodium bicarbonate as a carbon source in Nile tilapia nursery. The treatment with the highest feeding rate (TE) presented the highest consumption of alkalinizer per produced fish biomass, differing from the other treatments (Table 2).

Silva et al. (2020) evaluated different feeding rates (100, 75, and 50% of satiety) in Nile tilapia juveniles (30 to 150 g) in a mature biofloc system with the addition of inorganic carbon (similar to this study), where the final productivities averaged between 8.9 and 12.7 kg m^{-3}. This was similar to treatments TB, TC, TD, and TE in this study. The above mentioned authors also observed that the increase in the feeding rate resulted in a decrease in DO and an increase in TAN and nitrate. However, peaks of 5.8 mg of TAN L^{-1} and 1.6 mg N-NH_3 L^{-1} were observed with 100% satiety, harmful values for the species (Silva et al., 2019).

Unlike this study Silva et al. (2020) observed that the higher feed rate did not change the nitrite concentration in the water, and decreased pH and alkalinity values. This is due to the higher nitrification rate required in rearing with a higher feed rate, which results in higher carbonate consumption and greater release of H+ ions by nitrification. (Robles-Porchas et al., 2020). The divergence in the pH and alkalinity alterations between the studies is likely due to the different management options adopted for the use of alkalizing agents. In terms of nitrite, differences may not have been observed in the study by Silva et al. (2020), as the authors submitted the experimental units to 5% water renewal per day.

SS and TSS were higher in the treatments with the highest feeding rate (TE), reaching maximum values of 77 mL L^{-1} and 1,182 mg L^{-1} (Table 3), respectively. Silva et al. (2020) also observed higher values of SS and TSS with higher feeding rates, having reportedmaximum values of 225 mL L^{-1} and 1,450 mg L^{-1} of solids throughout the rearing of tilapia juveniles when fed with 100% of the satiety. Tilapia nursery studies in a biofloc system demonstrated a wide variation in the values of SS (0.5 to 65 mL L^{-1}) and TSS (200 to 1,600 mg L^{-1}) (Martins et al., 2017, Lima et al., 2018, Martins et al., 2019, Correa et al., 2020, Durigon et al., 2020, Hisano et al., 2020, Vicente et al., 2020). In this study, the solids were managed to maintain mean values close to 30 mL L^{-1} and 600 mg L^{-1}. It was, however, difficult for these values to be maintained in treatment TE.

Table 2: Water quality parameters of Nile tilapia nursery in a biofloc system as per the different feeding management options for 49 days.

Water quality parameters	TA	TB	TC	TD	TE	p-value
Temperature (°C)	28.5±0.1 (26.8–30.0)	28.5±0.1 (27.8–30.0)	28.3±0.2 (27.1–30.0)	28.4±0.2 (26.1–29.9)	28.4±0.1 (27.3–30.0)	0.172
Dissolved oxygen (mg L^{-1})	7.0±0.1^{A} (6.2–8.0)	6.7±0.1^{B} (5.5–7.8)	6.6±0.1^{BC} (5.4–7.7)	6.5±0.1^{BC} (5.7–7.9)	6.4±0.1^{C} (4.4–7.6)	0.001
pH	7.1±0.1^{B} (6.4–7.7)	7.2±0.1^{AB} (6.2–7.8)	7.3±0.1 ^{AB} (6.7–8.0)	7.3±0.1 ^{AB} (6.5–7.9)	7.4±0.1^{A} (6.6–7.9)	0.019
TAN (mg L^{-1})	0.15±0.04^{B} (0.00–1.48)	0.22±0.05^{AB} (0.00–1.56)	0.26±0.02^{A} (0.01–1.16)	0.26±0.05^{A} (0.00–2.17)	0.26±0.02^{A} (0.01–1.43)	0.003
N-Nitrite (mg L^{-1})	0.23±0.02^{B} (0.04–1.20)	0.62±0.17^{A} (0.04–2.90)	0.98±0.26^{A} (0.06–3.50)	0.75±0.47^{A} (0.05–4.70)	0.78±0.27^{A} (0.08–3.30)	0.002
N-Nitrate (mg L^{-1})	265±44^{AB} (75–370)	229±18^{B} (84–384)	267±15^{AB} (70–468)	299±30^{A} (77–510)	301±9^{A} (72–516)	0.008
Alkalinity (mg $CaCO_3$ L^{-1})	75±3^{C} (36–164)	83±6^{CB} (27–170)	92±11^{AB} (30–190)	95±7^{AB} (30–200)	99±4^{A} (30–190)	0.001
Hardness (mg L^{-1})	170±15 (125–240)	176±18 (130–300)	177±13 (140–250)	164±3 (125–200)	173±18 (124–300)	0.772
Relative alkalinizing consumption (%)	14.98±0.50^{A}	14.45±0.35^{B}	13.99±0.24^{BC}	13.75±0.26^{c}	13.95±0.21^{BC}	0.001
Alkalizing by biomass (g kg^{-1})	184±6^{B}	175±7^{B}	178±6^{B}	182±10^{B}	203±8^{A}	0.001

TAN: total ammonia nitrogen. Data are expressed as mean±standard deviation (maximum-minimum). Different letters represent statistically significant differences (p<0.05) between treatments in Tukey's test.

The higher the feeding rate, the greater the amount of solids produced per experimental unit (Table 3) and, consequently, the greater the need to remove these solids. Therefore, feeding management strategies must be adopted that produce fewer solids without worsening the zootechnical performance of tilapia juveniles and increasing the cost of their removal. It was also observed that higher feeding rates produced more solids per tilapia biomass produced. Treatment TE produced an average of 179 g of solids per kilo of produced juveniles, 208% higher than the treatment with a lower feed rate (TA), which produced 83 g of solids produced per kilo.

Zootechnical performance

Treatments TC, TD, and TE presented the highest values of FW, SGR, DWG, and yield (Table 4). Oliveira et al. (2021) determined that the feed rate for the better growth of juvenile tilapia in a biofloc was 6.1% of body weight, a mean value similar to the TC treatment in this study. However, the feeding management considered in this study by the TC treatment takes into account the adjustment of the feeding rate according to different body weights.

The treatment with the highest feeding rate demonstrated a FCR of 1.45, significantly different from the other treatments, which presented FCR between 1.21 and 1.32. Silva et al. (2020) also observed that the increase in the feeding rate improved the growth of tilapia juveniles. However, when they were fed to 100% satiety, there was a loss in FCR compared to the other feeding rates (50% and 75% satiety). Silva et al. (2020) concluded that for tilapia between 30 and 150 g, feeding to satiety may not be the best option in a biofloc system, considering there was a deterioration in water quality in addition to a loss in feed conversion. In this study, the higher FCR in the TE treatment may also be associated with lower quality in the water parameters, primarily due to the higher amount of solids, which reached values above 1,100 mg L^{-1} in the last week. According to Manduca et al. (2020), the greater amount of solids produced in a biofloc system can worsen the tilapia zootechnical performance.

The treatment with the lowest feeding rate, in addition to the lowest growth and yield values, demonstrated less uniformity compared to the other treatments (Table 4). However, the decrease in the feed supply did not affect survival, which did not differ betweenthe different feeding management options, and presented average values above 96.5%. Silva et al. (2020) and Oliveira et al. (2021) also observed that the different feeding rates in the rearing of Nile tilapia in bioflocs did not alter survival. The high survival obtained in this study was also similar to other studies on the tilapia nursery phase in bioflocs (Lima et al., 2018; Sgnaulin et al., 2020; Hisano et al., 2021) and superior to others that reported survival between 77 and 90% (Martins et al., 2017, 2019; Vieira et al., 2019; Oliveira et al., 2021).

Body assessment

In the results, it was observed that the higher feeding rate resulted in a decrease in nitrogen retention and protein efficiency rate (Table 5).

Silva et al. (2020) also observed that increasing the feeding rate in tilapia rearing in bioflocs decreased the PER, but with no effect on protein retention. They observed PER and protein retention values close to 2.6% and 42.5%, respectively, which were higher than those of this study. This difference may be related to the use of sugar as a carbon source, which did not occur in this study. It is known that the use of organic carbon sources, such as sugar in biofloc systems, stimulates the control of ammonia through the heterotrophic pathway, transforming it into bacterial biomass, which can later be used as a feed source by fish (Avnimelech, 2007).

Table 3: Solids analysis in Nile tilapia nursery in a biofloc system as per the different feeding management options for 49 days.

Solid parameters	TA	TB	TC	TD	TE	p-value
Settleable solids (mL L^{-1})	29.6±3.2^{AB} (18–46)	29.2±1.4^{B} (18–42)	27.9±3.0^{B} (14–44)	32.5±4.5^{AB} (20–58)	38.0±5.7^{A} (17–77)	0.015
Total suspended solids (mg L^{-1})	543±34^{D} (394–732)	604±14^{C} (421–828)	642±30^{BC} (417–932)	686±16^{B} (399–1.028)	751±25^{A} (405–1.182)	0.001
Total solids production (g $tank^{-1}$)	40±7^{D}	68±5^{D}	106±12^{C}	139±19^{B}	193±19^{A}	0.001
Solids produced by biomass (g kg $fish^{-1}$)	83±14^{C}	92±6^{C}	110±10b^{C}	140±28^{B}	179±15^{A}	0.001

Data are expressed as mean ±standard deviation (maximum-minimum). Different letters represent statistically significant differences (p<0.05) between treatments in Tukey's test.

Table 4: Zootechnical parameters of Nile tilapia nursery (2.37 ±0.55 g initial weight) in a biofloc system as per the different feeding management options for 49 days.

Parameters	TA	TB	TC	TD	TE	p-value
Final weight (g)	16.2±0.7^{C}	24.0±0.5^{B}	30.7±1.5^{A}	31.3±2.4^{A}	34.0±1.8^{A}	0.001
SGR (%)	3.92±0.09^{C}	4.72±0.04^{B}	5.23±0.11^{A}	5.25±0.16^{A}	5.43±0.12^{A}	0.001
DWG (g day^{-1})	0.28±0.01^{C}	0.44±0.01^{B}	0.58±0.03^{A}	0.59±0.05^{A}	0.65±0.04^{A}	0.001
FCR	1.23±0.01^{C}	1.21±0.03^{C}	1.27±0.02^{BC}	1.32±0.06^{B}	1.45±0.07^{A}	0.001
Yeild (kg m^{-3})	5.64±0.16^{D}	8.19±0.23^{C}	10.41±0.32^{B}	10.91±0.84^{AB}	11.65±0.68^{A}	0.001
Survival (%)	99.3±1.4	97.9±2.7	97.1±2.3	96.5±1.5	97.9±1.4	0.389
Uniformity (%)	41.7±5.0^{B}	51.8±2.4^{AB}	55.1±7.6^{A}	52.0±8.5^{AB}	61.3±3.8^{A}	0.005

SGR: specific growth rate, DWG: daily weight gain, FCR: feed conversion rate. Data are expressed as mean ±standard deviation. Different letters represent statistically significant differences ($p<0.05$) between treatments in Tukey's test.

Table 5: Body assessments of Nile tilapia juveniles reared in a biofloc system as per the different feeding management options for 49 days.

Parameters	TA	TB	TC	TD	TE	p-value
Nitrogen retention (%)	34.4±1.5^{AB}	35.5±0.5^{A}	32.9±1.9^{AB}	31.6±1.1^{BC}	29.0±1.5^{C}	0.001
PER (%)	2.03±0.02^{A}	2.07±0.04^{A}	1.99±0.03^{AB}	1.90±0.08^{B}	1.73±0.08^{C}	0.001
HSI (%)	2.59±0.36^{B}	3.11±0.46^{B}	3.62±0.16^{AB}	3.57±0.20^{AB}	4.62±0.87^{A}	0.001
VF (%)	2.26±0.33^{C}	2.54±0.10^{CB}	3.10±0.34^{AB}	3.37±0.51^{A}	3.64±0.15^{A}	0.001

Data expressed as mean ±standard deviation. PER: protein efficiency rate, HSI: hepatosomatic index, VF: visceral fat. Different letters represent statistically significant differences ($p<0.05$) between treatments in the Tukey test.

Studies also prove that rearing with biofloc systems while prioritizing the heterotrophic phase rather than the chemoautotrophic phase, results in flocs with a higher protein level (Ahmad et al., 2017). Instead of reducing ammonia nitrogen into nitrate, it will be transformed into microbial protein and made available again as feed for the juveniles of tilapia.

In this study, an increase in the HSI and VF was observed with increasing feeding rate, corroborating Silva et al. (2020) and Oliveira et al. (2021). The HSI values obtained with the lower feeding rate treatment in this study were similar to HSI values obtained by Durigon et al. (2020); Silva et al. (2020) and Oliveira et al. (2021) with tilapia rearing in biofloc. However, the highest feeding rates treatments demonstrated higher HSI values than those of other studies. Studies of viscerosomatic indices, such as HSI and VF, play an important role in understanding fish feed metabolism (Ighwela; Ahmad; Abol-Munafi, 2014). Huang et al. (2015) also evaluated the effect of different feeding rates for tilapia juveniles in clear water and observed that the increase in HSI with increasing feeding rates was accompanied by an increase in the percentage of liver fat and body fat in tilapia. The authors also reported that excessive feeding for tilapia caused histopathological lesions in the liver, as well as an increase in blood cholesterol and triglycerides, potentially leading to health problems.

CONCLUSIONS

It is recommended that the feed management used in the TC treatment be used in tilapia nurseries with a biofloc system, using 26% below the highest feed rate. High feed rates cause a reduction in the utilization of protein nitrogen, and an increase in nitrogen compounds and solids in the water, leading to a worsening in the FCR. The excess feed supplied to tilapia reared in a biofloc causes an increase in HSI and VF. On the other hand, very low feeding rates cause a decrease in growth and uniformity of tilapia juveniles.

AUTHOR CONTRIBUTIONS

Conceptual Idea: Silva, B.C.; Vieira, F.N. Methodology design: Silva, B.C.; Vieira, F.N.; Serafini, R.L. Data collection: Silva, B.C.; Rosa, K.V.; Haluko, M.; Serafini, R.L. Data analysis and interpretation: Silva, B.C.; Rosa, K.V.;

Vieira, F.N.; Serafini, R.L. Writing and editing: Silva, B.C.; Haluko, M.; Rosa, K.V.; Vieira, F.N.; Serafini, R.L.

ACKNOWLEDGMENTS

The authors are grateful for the technical support from the collaborators Silvio Demarch Filho, Leandro Bortoli, Emidio Sant'Anna de Lara and Karla Geovana Weiss de Souza. The authors are additionally grateful to the company Guabi Nutrição e Saúde Animal for supplying the feed, and to the UFSC LABNUTRI Laboratory, for nitrogen retention analyses. This research was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil (project 409598/2018–6).

REFERENCES

AHMAD, I. et al. Biofloc technology: An emerging avenue in aquatic animal healthcare and nutrition. Aquacultulture International, 25(3):1215-1226, 2017.

ALVARENGA, É. R. et al. Moderate salinities enhance growth performance of Nile tilapia (*Oreochromis niloticus*) fingerlings in the biofloc system. Aquaculture Research, 49(9):2919-2926, 2018.

ALVES, G. F. et al. Effect of the transfer at different moments of juvenile Nile tilapia (*Oreochromis niloticus*) to the biofloc system in formation. Aquaculture, 479:564-570. 2017.

AMANY, A. G. et al. Influence of dietary protein level and feed inputs on growth and feeding performance of the Nile tilapia under biofloc conditions. Egyptian Journal of Aquatic Biology and Fisheries, 23(3):483-491, 2019.

AMERICAN PUBLIC HEALTH ASSOCIATION - APHA. Standard methods for the examination of water and wastewater. 22st ed. American Public Health Association, Washington, DC, USA, 2012. 1504p.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS - AOAC. Official methods of analysis of AOAC international. 16th Edition, Arlington, VA, 1999.

AVNIMELECH, Y. Feeding with microbial flocs by tilapia in minimal discharge bioflocs technology ponds. Aquaculture, 264(1-4):140-147, 2007.

AVNIMELECH, Y. Biofloc technology: A practical guide book. Baton Rouge, Louisiana, 2nd ed., United States: The Word Aquaculture Society, 2012. 271p.

BOSSIER, P.; EKASARI, J. Biofloc technology application in aquaculture to support sustainable development goals. Microbial Biotechnology, 10(5):1012-1016, 2017.

CALDINI, N. N. et al. Feeding Nile tilapia with artificial diets and dried bioflocs biomass. Acta Scientiarum. Animal Sciences, 37(4):335-341, 2015.

CAVALCANTE, D. H. et al. Single or paired increase of total alkalinity and hardness of water for cultivation of Nile tilapia juveniles, *Oreochromis niloticus*. Acta Scientiarum. Technology, 34(2):177-183, 2012.

CAVALCANTE, D. H. et al. Imbalances in the hardness/alkalinity ratio of water and Nile tilapia's growth performance. Acta Scientiarum. Technology, 36(1):49-54, 2014.

CORREA, A. D. S. et al. Rearing of Nile tilapia (*Oreochromis niloticus*) juveniles in a biofloc system employing periods of feed deprivation. Journal of Applied Aquaculture, 32(2):139-156, 2020.

DURIGON, E. G. et al. Biofloc technology (BFT): Adjusting the levels of digestible protein and digestible energy in diets of Nile tilapia juveniles raised in brackish water. Aquaculture and Fisheries, 5(1):42-51, 2020.

FRIES, J.; GETROST, H.; MERCK, D. E. Organic reagents trace analysis. Germany: E. Merck Darmstadt, 1977. 453p.

HISANO, H. et al. Dietary protein reduction for Nile tilapia fingerlings reared in biofloc technology. Journal of the World Aquaculture Society, 51(2):452-462, 2020.

HISANO, H. et al. Effect of feeding frequency on water quality, growth, and hematological parameters of Nile tilapia *Oreochromis niloticus* reared using biofloc technology. Journal of Applied Aquaculture, 33(2):96-110, 2021.

HUANG, Q. et al. Feeding frequency and rate effects on growth and physiology of juvenile genetically improved farmed Nile Tilapia. North American Journal of Aquaculture, 77(4):503-512, 2015.

IGHWELA, K. A.; AHMAD, A. B.; ABOL-MUNAFI, A. B. The selection of viscerosomatic and hepatosomatic indices for the measurement and analysis of *Oreochromis niloticus* condition fed with varying dietary maltose levels. International Journal of Fauna and Biological Studies, 1(3):18-20, 2014.

JATOBÁ, A.; BORGES, Y. V.; SILVA, F. A. BIOFLOC: Sustainable alternative for water use in fish culture. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 71(3):1076-1080, 2019.

LIMA, P. C et al. Nile tilapia fingerling cultivated in a low-salinity biofloc system at different stocking densities. Spanish Journal of Agricultural Research, 16(4):e0612, 2018.

LÓPEZ-ELÍAS, J. A. et al. Proximate composition of bioflocs in culture systems containing hybrid red tilapia fed diets with varying levels of vegetable meal inclusion. North American Journal of Aquaculture, 77(1):102-109, 2015.

MANDUCA, L. G. et al. Effects of a zero exchange biofloc system on the growth performance and health of Nile tilapia at different stocking densities. Aquaculture, 521:735064, 2020.

MARTINS, G. B. et al. The utilization of sodium bicarbonate, calcium carbonate or hydroxide in biofloc system: Water quality, growth performance and oxidative stress of Nile tilapia (*Oreochromis niloticus*). Aquaculture, 468:10-17, 2017.

MARTINS. G. B. et al. Growth, water quality and oxidative stress of Nile tilapia *Oreochromis niloticus* (L.) in biofloc technology system at different pH. Aquaculture Research, 50(4):1030-1039, 2019.

MONSEES, H. et al. Chronic exposure to nitrate significantly reduces growth and affects the health status of juvenile Nile tilapia (*Oreochromis niloticus* L.) in recirculating aquaculture systems. Aquaculture Research, 48(7):3482-3492, 2017.

OLIVEIRA, L. K. et al. Growth, nutritional efficiency, and profitability of juvenile GIFT strain of Nile tilapia (*Oreochromis niloticus*) reared in biofloc system on graded feeding rates. Aquaculture, 541:736830, 2021.

PIEDRAS, S. R. N. et al. Comparação entre o selênio orgânico e o inorgânico empregados na dieta de alevinos de jundiá (*Rhamdia quelen*). Boletim do Instituto de Pesca, 31(2): 171-174, 2005.

POLI, M. A. et al. Pacific white shrimp and Nile tilapia integrated in a biofloc system under different fish-stocking densities. Aquaculture, 498:83-89, 2019.

PRABU, E. et al. Effect of dietary supplementation of biofloc meal with tryptophan on growth and survival of GIFT Tilapia. International Journal of Current Microbiology and Applied Sciences, 6(8):3426-3434, 2017.

ROBLES-PORCHAS, G. R. et al. The nitrification process for nitrogen removal in biofloc system aquaculture. Reviews in Aquaculture, 12(4):2228-2249, 2020.

SGNAULIN, T. et al. Nutrition of genetically improved farmed tilapia (GIFT) in biofloc technology system: Optimization of digestible protein and digestible energy levels during nursery phase. Aquaculture, 521:734998, 2020.

SILVA, M. A. et al. Crude protein levels in diets for two growth stages of Nile tilapia (*Oreochromis niloticus*) in a biofloc system. Aquaculture Research, 49(8):2693-2703, 2018.

SILVA, B. C. et al. Monocultivo de tilápia em viveiros escavados em Santa Catarina. (Sistemas de Produção, 52). Florianópolis: Epagri, 2019. 126p.

SILVA, M. A. et al. Feeding management strategies to optimize the use of suspended feed for Nile tilapia (*Oreochromis niloticus*) cultivated in bioflocs. Aquaculture Research, 51(2):605-615, 2020.

VICENTE, L. R. M. et al. Nile tilapia nursery in a biofloc system: Evaluation of different stocking densities. Boletim do Instituto de Pesca, 46(2):e573, 2020.

VIEIRA, R. B. et al. Zootechnical performance evaluation of the use of biofloc technology in Nile tilapia fingerling production at different densities. Boletim do Instituto de Pesca, 45(4):1678-2305, 2019.