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Growth and Feed Performances of the Nile Tilapia During the Fattening Stage Under Restricted Feeding in Biofloc Culture

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ABSTRACT

The Nile tilapia was raised in biofloc culture to evaluate growth performance during the fattening stage and water quality dynamics. The current experiment was designed to test the effect of rearing tilapia under different restricted feeding rates amounted to 1.2, 1.4 and 1.6% of fish biomass compared to that of the control treatment, with a feeding level of 2.0% in biofloc culture. Treatments were equally replicated in duplicate tanks per treatment. The optimum restricted feeding rate during the current experiment was observed when fish were fed at 1.4% feeding rate compared to that of the control treatment. Consequently, fish should be fed at lower feed inputs in biofloc culture compared to the control since neither daily weight gain nor feed conversion ratio was improved when the control feed input was employed. Final biomass harvest/m^3 ranged from 3.17 to 4.17 kg/m^3 by the end of the fourth month during the experimental period was obtained. When reducing the dietary feeding rate to 1.4, no negative effect on the expected fish harvest. This indicated that juvenile tilapia can obtain supplementary nutrition from feeding on suspended biofloc material in tank water. Feed conversion ratios were improved in the 1.4% and 1.6% feed inputs (1.57 and 1.96, respectively) when compared to the control treatment (2.43). This result reflected the positive effect of biofloc material as a source of nutrition for Nile tilapia during the fattening process. Consequently, it can be concluded that restricted feeding should be adopted when fish are raised in biofloc environment in order to reduce feed costs and increase profitability

INTRODUCTION

RAS system was considered the major intensive aquaculture system for decades; however, higher implementation and operation costs prevented its spread as an intensive technology. Consequently, biofloc technology is considered more economically effective than RAS in terms of cost benefit ratio **(Luo *et al*., 2014)**.

The Nile tilapia represents a filter feeder fish that can ingest biofloc material in suspension as a supplementary feed, and consequently increasing feed efficiency, being a successful candidate for biofloc culture. The basic concept in biofloc technology depends on the use of microbial biomass by cultured fish as complementary food source **(Schryver *et al*., 2008)**.

Commercial feed makes up more than 60% of running cost in tilapia culture, and thus using restricted feeding decreases feed volume consumed by fish as well as feeding labor, especially when biofloc technology is implemented in tilapia culture **(Correa *et al*., 2020)**. Tilapia would benefit from feeding on microbial flocs during partial feed deprivation when restricted feeding is employed.

Roch *et al*. (2019) pointed out that over-feeding results in the deterioration of water quality; moreover, over-feeding reduces farm profits since feed costs comprise 60-70% of the running cost involved in fish culture **(Paningrahi *et al*., 2017)**. At the same time, biofloc material produced is a free cost supplementary food that can be used for culturing fish **(Crab *et al*., 2012)**.

Oliveira *et al*. (2021) supported the importance of merging economic and growth performance of the Nile tilapia in order to meet local market techniques used to set up optimum feed management practices. According to recent literature, this knowledge is not well-defined for the fattening stage of tilapia biofloc culture.

In applied situation, restricted feeding employed by fish farmer always results in better feed conversion ratio than that attained by ad libitum feeding **(Oliveira *et al*., 2021)**. Generally, studies on the Nile tilapia performance under biofloc conditions were employed where fish were fed until satiation; since in BFT culture, it is not feasible to precisely estimate food consumption **(Durigon *et al*., 2020)**.

Consequently, feed management affects the sustainability of aquaculture **(Ogello *et al*., 2014)**. Size of fish appears to influence the filtration rate of the Nile tilapia to food particles **(Oliveira *et al*., 2021)**, where it is documented that the filtration rate of algal matter decreases with increasing fish size **(Turker *et al*., 2003)**. The Nile tilapia has been documented to efficiently consume biofloc microorganisms at the juvenile stage than the fattening stage **(Alves *et al*., 2017; Bossier & Ekasari 2017; Sousa *et al*., 2019)**. Moreover, suspended biofloc is regarded as a supplementary protein rich feed for the Nile tilapia **(Hisano *et al*., 2019)**. This, in return, contributes to lower production costs **(Prabu *et al*., 2017)**.

Although some investigations have determined the effect of different dietary protein levels on the Nile tilapia culture under biofloc conditions, none of them recognized the effect of feeding rate levels on the Nile tilapia raised during the fattening stage in biofloc culture. Amazingly, none of published investigations were found in the literature that dealt with the effect of feeding rate on the growth performance of the Nile tilapia juvenile during the fattening stage and until the market size in biofloc culture.

The objective of the current study was to assess the growth and feed performances of the Nile tilapia, as well as addressing water quality dynamics under restricted feeding during the fattening stage when reared in biofloc technology.

MATERIALS AND METHODS

The study was conducted in the Fish Culture Research Unit, Faculty of Agriculture, Cairo University, Egypt, during June 2019 to October 2019. A static outdoor rearing system was used to carry out the experiment. Rectangular concrete tanks (2.2*1.2*1.0 m) were filled with fresh water obtained from a well. Eight concrete tanks were used in the current experiment. Each tank had a water volume of $2.0m^3$, with a water depth of 75cm. Juveniles of the Nile tilapia, *Orechromis niloticus* (with average weights of 105.9-109.2 g/fish) were randomly distributed among experimental tanks, with duplicate tanks per treatment. Each tank contained 32 juveniles of the Nile tilapia. The experimental duration lasted for 122 days during warm season.

1. Experimental design

The Nile tilapia was raised in biofloc culture to evaluate growth performance during the fattening stage and water quality dynamics. The current experiment was designed to test the effect of rearing tilapia under different restricted feeding rates that amounted to 1.2, 1.4 and 1.6% of fish biomass, compared to that of the control treatment which had a feeding level of 2.0% in biofloc culture. A total of 256 fish were randomly distributed at the rate of 32 juveniles per tank. Treatments were equally replicated in duplicate tanks per treatment and arranged in completely randomized design.

Fish were daily fed for six days a week during the experimental period. Fish were fed on both diet material and biofloc matter in rearing tanks. Artificial diet contained 31.1% crude protein, 4% crude fat, 44.7% NFE, 3.7% crude fiber, 7.5% ash and 9% moisture.

Artificial aeration continued 24 hours a day, all days of the week, using a blower. Ground corn as a source of carbon was scattered over water surface in each tank at dry feed to ground corn ratio of 2:1 daily in order to develop biofloc and nourish heterotrophic bacteria. This was equivalent to 50% of the daily diet weight. Water was renewed on a monthly basis in each tank to reduce sludge and suspended organic matter.

2. Growth and feed performance

Fish in each tank were weighed and counted at the start and end of the experiment that lasted 122 days during warm season. Growth performance of cultured fish was measured in terms of final individual fish weight (g), weight gain (g/fish), daily weight gain (g/fish/day) and specific growth rate (SGR-% day). Feed performance was measured in terms of feed conversion ratio (FCR) and protein efficiency ratio (PER). Biomass performance was measured in terms of initial and final biomass/m3, biomass gain per cubic meter of water and survival rate of cultured fish. Individual weights of fish were measured at the beginning and end of the experiment using digital balance to the nearest 0.1g.

Weight gain = final weight - initial weight

Daily weight gain= (final body weight–initial body weight)/experiment period (days).

Biomass gain/ pond = final biomass – initial biomass

Biomass gain/m^3 = biomass gain per pond/2

Survival rate = (final count/initial count) x 100

Specific growth rate = $(\ln W_T - \ln W_0) \times (100) / t$

Where, W_T: final weight at time t; W_0 is initial weight, and t is the duration of time in days.

Feed conversion = dry weight of feed fed (g)/ fish weight gain (g).

Protein efficiency ratio = fish biomass gain (g) / protein fed.

Initial biomass/m^3 = (average initial weight of fish x fish density per pond)/ 2

Final biomass/m^3 = (average final weight of fish x fish density per pond)/ 2

Harvest weight/fish = (fish biomass/tank) / fish density

3. Water quality analysis

All determinations of water quality parameters were carried out in the Fish Research Unit (Faculty of Agriculture, Cairo University) according to **Boyd and Tucker (1998)**. Temperature and dissolved oxygen parameters were measured using HANNA Instrument dissolved oxygen meter. Water temperature was taken at 10 a.m. in the morning. Dissolved oxygen was taken by integrating the probe of oxygen over the whole depth of water up to the bottom of the tank. The pH was measured on site by pH digital meters in the morning. Biofloc volume or settling solids (SS, ml/l) in each tank was measured using the Imhoff cone (one liter capacity), where water was loaded with water containing the biofloc up to the one liter mark and left to settle for 30 minutes before reading the biofloc volume. Estimates of Secchi disk visibility were made at the same time of biofloc sampling in each concrete tank.

Nitrite-nitrogen was measured using the diazotizing method employing colorimetric method (Lovibond water testing meter). Total ammonia concentration in tank water was measured using the indophenols method (Phenate method). Indophenol gives the solution of blue color which was measured using colorimeter (Lovibond water testing, meter). Water samples were filtered through 0.45 microfilter membranes before analysis.

4. Statistical analysis

Growth performance of the cultured fish and water quality parameters in culture tanks were subjected to one-way analysis of variance to determine significant statistical differences among treatments. Differences among means were estimated by Duncan's multiple range test **(Duncan, 1955)**. Significant differences were determined by setting type I error at 5% for each comparison. These statistical analyses were performed using the software package SPSS for windows, Release 8.0 **(SPSS, 1997)**.

RESULTS AND DISSCUSION

1. Water quality parameters

1.1. Water temperature

Water temperature in the mornings ranged from 32.2- 32.8°C among treatment at the start of the experimental period during July 2019 (Table 1). There was a gradual decrease in water temperature over time during the experiment, reaching 26.2-26.8 °C by the end of the experimental in mid- October 2019. Optimal temperature for the growth of the Nile tilapia is known to range from 25- 30ºC according to **Boyd and Tucker (1998)**. Average of water temperature in experimental tanks during the study period ranged from 29.6- 30.3°C, with no significant differences among treatments (P>0.05).

1.2. Water pH

Overall, the mean water pH values ranged between 8.19 and 8.75 (Table 1) among the biofloc treatments, with significant differences among feed inputs treatments (P<0.05). The control and the 1.6% feed input treatments had lower pH values (8.19- 8.29 units), compared to the lower feed input treatments (1.2 and 1.4% feed inputs), which had higher water pH values, ranging from 8.74- 8.75 units. **Ridha *et al*. (2020)** postulated that, biofloc tanks had lower pH values (P<0.05) than non-biofloc tanks.

Karunarachchi *et al*. (2018) justified the gradual decrease of pH in biofloc culture to the increase in CO_2 concentration in water due to respiration of microorganisms and fish. Consequently, it is concluded that water pH in biofloc treatments is controlled by feed inputs, with negative relationship between the two variables. The reduction of pH value in biofloc water may be due to the consumption of carbonate and bicarbonate ions by bacterial community, which decreases calcium carbonate in water and reduces pH levels **(Alvarenga *et al*., 2018)**.

1.3. Dissolved oxygen concentration

The respiration rate of biota in indoor brown water biofloc culture is normally 6 mgO_2/l/hour, excluding fish respiration which is normally at 5-8 mgO_2/l/hour, with a total respiration rate at 12 mgO_2/l/hour **(Choo & Caipang, 2015)**.

The pattern of overall mean oxygen concentrations during the current experiment indicated slight variation in dissolved oxygen concentrations in tank water, where dissolved oxygen ranged from 4.8- 6.1mg/ l among treatments, with significant differences among means (P<0.05). Dissolved oxygen concentrations were slightly higher with lower feed inputs (5.9-6.1 mg/l) due to the variation in feed inputs and its effect on community respiration rates (Table 1).

The observed oxygen concentrations in tank water during the current experiment were at the recommended oxygen concentrations level for fish culture (5.0 mg/l) according to **Boyd and Tucker (1998)**. In the current experiment, aeration supplied oxygen as well as created water mixing and agitation to suspended biofloc particles in tank water.

1.4. Secchi disk and biofloc volume

All biofloc treatments have shallower photic depths (9.7-10.5cm), with no significant differences among means (P>0.05). Secchi disk readings observed in the current experiment indicated dense suspension of biofloc material and bacteria available for the Nile tilapia nutrition (Table 1). **Crab *et al*. (2012)** and **Hargreaves (2013)** indicated that fish chosen to biofloc culture should tolerate high levels of suspended solids and should be able to filter feed on biofloc matter as natural food such as tilapia and carp. The dense abundance of biofloc matter was due to the excretion of ammonia by fish in addition to the application of ground corn at 50% of feed inputs daily.

Biofloc abundance in culture tanks was estimated by Imhoff volumes and Secchi disk parameters to explain the abundance of biofloc materials in terms of its effect on nutrition of fish. Biofloc volumes in rearing tanks were nearly similar over time during the experiment due to the total renewal of water on a monthly basis. Many authors recommended the use of flushing procedure to retain low biofloc volumes in culture tanks **(Preze-Fuentes *et al*., 2016)**, water renewal **(Manduca *et al*., 2021)** or water clarification **(Luo *et al*., 2014)**.

Ranges of biofloc volumes (settling solids SS) as indices of biofloc material and water turbidity were within the acceptable limits recommended in biofloc systems, considering sound water quality management in fish farming. At higher feed load, biofloc abundance was positively affected due to the increase in fish excretion augmented by high corn input. Overabundance of nitrogen and phosphorus salts in the control treatment increased suspended biofloc (SS) in the water column (SS= 23.6 ml/l). Several studies attributed the increase in biofloc volume (BFV) determined by Imhoff cones to the increase in feed input and supplementation of organic carbon **(Xu *et al*., 2016; Liu *et al*., 2017; Adineh *et al*., 2019)**.

Biofloc volumes were nearly similar among restricted treatments over time (P>0.05) although different feed inputs were applied within the restricted treatments. The average biofloc volume readings in the control treatment (23.6 ml/l) were significantly higher (Table 1), compared to those of the restricted feeding treatments (8.9-10.6 ml/l), which were due to the increased biofloc abundance in the control treatment compared to other treatments (P<0.05). This can be justified by the higher feed inputs applied in the control treatment.

Acceptable range of settling solids (SS) 25-50 ml/l for tilapia culture was recommended in biofloc water by several studies **(De-Schryver *et al*., 2008; Ray *et al*., 2010; Hargreaves, 2013; Green *et al*., 2014; Emerenciano *et al*., 2017; Lima *et al*., 2018; Ridha *et al*., 2020)**. **Dos Santos *et al*. (2021)** suggested tolerance limits to SS values in biofloc water up to 50 ml/l. Feeding rates employed in the current experiment produced a very shallow visibility depth (9.7-10.5 cm) and prevented algal development in tank water during the study period. Averages Imhoff readings (8.9-23.6 ml/l) among feeding rate treatments were within the optimal range recommended in the biofloc culture of fish. This optimal range was created by the monthly total renewal of water in biofloc tanks.

Table 1. Water quality dynamics under different feeding rates of Nile tilapia during the fattening stage using biofloc technology

Parameter	Feeding rates			
	control	1.6%	1.4%	1.2%
Ammonia (mg/l)	0.449±0.01^{a}	0.318±0.005^{b}	0.347±0.043^{b}	0.325±0.011^{b}
Nitrite (mg/l)	0.696±0.056^{ab}	0.538±0.162^{bc}	0.386±0.009^{cd}	0.284±0.045^{d}
Oxygen (mg/l)	4.86±0.101^{b}	5.13±0.836^{b}	6.11±0.326^{a}	5.92±0.107^{a}
pH	8.19±0.016^{b}	8.29±0.118^{b}	8.75±0.126^{a}	8.74±0.023^{a}
Temperature (°C)	29.61±0.050^{c}	29.86±0.075^{b}	29.95±0.137^{b}	30.31±0.156^{a}
Secchi disk (cm)	9.89±0.393^{a}	10.5±0.929^{a}	9.85±0.143^{a}	9.71±0.285^{a}
Settling solids (ml/l)	23.66±0.166^{a}	10.58±0.416^{c}	10.66±0.5^{c}	8.91±0.583^{d}

Means in the same row with different letters are significantly different (*P*<0.05)

1.5. Ammonia and nitrite values

Average total ammonia nitrogen concentrations (TAN) ranged from 0.31- 0.44mg/ l during the experiment and increased gradually to 0.56- 0.88mg/ l by the end of the experiment (Table 1). This was caused by the gradual increase of feed inputs per tanks along with the increase in growth of fish biomass within each treatment during the study period. No significant differences were observed in terms of TAN concentrations among treatments during the study.

The concentrations of TAN in water of the biofloc tanks were low due to the addition of ground corn at 50% of dietary inputs per day during the culture period. **Crab *et al*. (2012)** reported that, biofloc system functions as a biofilter (*in situ*) that removes ammonia and nitrite from culture water. The carbohydrate source enhances heterotrophic bacteria activities that absorb ammonia required for bacterial growth, resulting in a decrease of total ammonia (TAN) concentrations in water to a tolerable range **(Vieira *et al*., 2019)**. Ammonia removal in biofloc culture is accomplished through the combined action of heterotrophic bacteria, chemoautotrophic nitrifying bacteria and microalgae as reported in the studies of **Hargreaves (2006)** and **Xu *et al*. (2016)**.

The mean value of total ammonia nitrogen (TAN) were within the acceptable range considered suitable for the culture of the Nile tilapia, with no significant differences observed among treatments ($P>0.05$). The current study indicated that adding ground corn at 50% with daily ration inputs was suitable to complete the absorption of metabolic ammonia from water in biofloc tanks which resulted in reduced TAN concentrations in water medium where the Nile tilapia was raised. **Manduca *et al*. (2021)** and **Garcia-Rios *et al*. (2019)** showed that biofloc technology can be considered as corrective measures that sustain water quality parameters within a tolerable range to control toxic ammonia and nitrogen compounds.

Crab *et al*. (2007) justified this process as heterotrophic bacteria grow 10 times faster than nitrifying bacteria grown in biofilter. As a result, biofloc system is more efficient than "conventional biofilter" **(Crab *et al*., 2012)**.

When tilapia was cultured in biofloc system, ammonia concentrations were maintained below 1mg/ l during most of the experimental period, which were within tilapia culture tolerable range **(Kuhn *et al*., 2010; Perez Fuentes *et al*., 2016; Xu *et al*., 2016; Panigraphi *et al*., 2017; Magana-Gallegos *et al*., 2018; Sontakke & Haridas, 2018; Adineh *et al*., 2019; Gallardo-Colli *et al*., 2019; Manduca *et al*., 2021)**.

Two functional categories of bacteria are primarily responsible for water quality maintenance in minimal exchange intensive systems, heterotrophic ammonia assimilative and chemoautotrophic nitrifying bacteria **(Eding *et al*., 2006**; **Hargreaves, 2006)**. Nitrosomonas and Nitrobacter bacteria attach to organic matter suspended in the water column where they oxide toxic ammonia into nitrite, and nitrite into nitrate, respectively **(Timmons *et al*., 2007)**.

Overall, averages of nitrite concentrations in water in culture tanks ranged from 0.28-0.69mg NO2-N/l during the current study, indicating that Nitrosomonas and Nitrobacter bacteria were very efficient in transforming excreted ammonia into nitrite and nitrate (Table 1). Since very low nitrite concentrations were detected among all treatments during the study period. Water quality parameters in biofloc culture could be maintained at optimum levels when toxic ammonia and nitrite are converted to less toxic nitrate **(Caipang *et al*., 2019)**.

2. Growth performances

2.1. Average final body weight

Final harvest weights of the Nile tilapia were significantly different among the restricted and control treatments (P<0.05). The control treatment showed higher harvest weight (273.8 g/fish) above that obtained with the 1.2% restricted feed treatment, which averaged 223.5g/ fish at the end of the experiment (Table 2). However, no significant differences were observed between average harvest weight of the control treatment and the 1.4% - 1.6% restricted feed treatments, which averaged 258.1- 264.9 g/fish, respectively (P>0.05).

The harvest weight of the Nile tilapia obtained in the control treatment, where high feed input was applied, coincided with those of the Nile tilapia fed lower inputs (1.4 and 1.6% levels). Superior final harvest weight of the Nile tilapia was obtained when suspended biofloc concentration was at its highest, which was ascribed to the nutritious content of biofloc matter **(Martins *et al*., 2020)**.

2.2. Specific growth rate (SGR)

Specific growth rates of the Nile tilapia were higher among treatments at the start of the experiment (0.81-1.13% per day) when tilapia juveniles were small sized and decreased as fish grew during the experiment. The overall specific growth rates during the restricted feeding experiment ranged from 0.59- 0.75% per day among treatments, with the least SGR observed in the 1.2% feeding rate treatment (Table 2). **Nguyen *et al*. (2021)** ascertained the role of microbial flocs in supporting higher weight gain, SGR and better FCR in cultured tilapia. This finding agrees with those of several other studies **(Luo *et al*., 2014; Long *et al*., 2015; Mansour & Esteban, 2017)**.

Growth performance in terms of SGR in the 1.4% and 1.6% feeding rate treatments (0.71-0.74% per day) were the same as that of the control (0.75% per day) as fish were fed at 2.0%. The optimum restricted feeding rate during the current experiment was observed when fish were fed at 1.4% feeding rate, compared to that of the control treatment which was fed at 2% of fish biomass per day. It is concluded that, the Nile tilapia above 100g/ fish should be fed at 1.4% of biomass per day instead of 2% in biofloc supported system as slight variations were detected among dietary treatments. Additional nutrition from suspended biofloc material enabled similar growth performance of the Nile tilapia when fed at 1.4% per day, compared to the higher feeding rate adopted in the control treatment.

2.3. Weight gain per fish

Higher weight gain (164.5 g/fish) was observed in the control treatment compared to that of the 1.2% restricted feed treatment (114.4 g/fish). Lowering feeding rates to 1.4-1.6% in respect to the control treatment produced similar weight gains (149.4-159.0g/fish), without significant differences (P>0.05). When feeding rate was lowered to 1.4% of biomass, fish growth was not affected. Consequently, fish fed at lower feed inputs in biofloc culture compared to the control (2.0% of biomass) since neither daily weight gain nor feed conversion ratio was improved when the control feed input was employed (Table 2).

Haridas *et al*. (2017) explained that, better growth performance of tilapia in biofloc treatment was due to the optimum water quality and continuous availability of supplemental nutritious floc in water. Monosex fingerlings of the Nile tilapia cultured under biofloc system recorded highest weight gain and SGR compared to those reared in clear water system **(Eid *et al*., 2020)**. Several studies indicated that suspended biofloc matter (microbial flocs) improved weight gain and SGR of tilapia **(Luo *et al*., 2014; Long *et al*., 2015; Mansour & Esteban, 2017; Nguyen *et al*., 2021)**. Consequently, it can be concluded that, fish should not be fed at the lowest feed input at 1.2% of biomass when optimal weight gain is desired under the biofloc treatments. The results showed that there was no need for feeding fish at inputs higher that than 1.4% of biomass when feed would be applied in biofloc culture during the fattening stage.

2.4. Daily weight gain

Similar daily weight gains of the Nile tilapia were observed in the 1.4% and 1.6% restricted treatments (1.3 and 1.22 g/fish/day, respectively) compared to that of the control treatment (1.35 g/fish/day) in spite of reducing feeding rates (Table 2). This indicated that the Nile tilapia can obtain major nutrition requirements for growth from feeding on biofloc material providing optimum nutrition for fish during the experiment. **Adineh *et al*. (2019)** ascribed the positive effect on the growth performance of common carp in biofloc system to the stable and better water quality of the culture system where fish feed on filtered suspended biofloc material with good quality protein.

Widanarni *et al*. (2012) obtained daily weight gain of tilapia (0.52-1.39 g/day) when reared in biofloc culture, which was higher than that obtained by **Perez-Fuents *et al*. (2016)** with values range of 0.95- 1.24g/ day. Fish reared under restricted feed inputs had similar daily weight gains due to the availability of biofloc in high abundance in water in rearing tanks. Biofloc environment supports better water quality as well as provides good quality food source as supplemental food for fish **(Fauji *et al*., 2018).**

Consequently, it can be concluded that, restricted feeding should be adopted when fish are raised in biofloc environment in order to reduce feed costs and increase profitability. Decreasing feed input to 1.2% of biomass had negative effect on daily weight gain (0.93 g/fish/day) compared to other treatments, indicating that this level of feed input represents under-feeding (Table 2).

2.5. Final biomass harvest

Final biomass harvest/m^3 ranged from 3.17- 4.17kg/ m^3 by the end of the fourth month during the experimental period (Table 2), with significant differences among treatments (P<0.05). Similar biomass harvest (4.17 kg/m^3) was obtained when the Nile tilapia fish were fed at 1.4% of biomass, compared to that of the control treatment (4.1 kg fish/m^3), with no significant differences between treatments (P>0.05). Although the 1.4% feeding rate treatment had lower daily feed input compared to the control, similar biomass harvest was obtained in both treatments (*P*>0.05). Thus, reducing dietary feeding rate to 1.4% had no negative effect on expected fish harvest, indicating higher efficiency and profitability of reduced feeding rate.

Mahanand *et al*. (2013) pointed out that, biofloc matter produced in BFT is nutritious and can be used as food for herbivorous or omnivorous fish to obtain optimal growth. **Ekasari (2014)** denoted that, biofloc systems had higher net productivity compared to non-biofloc systems (recirculating aquaculture system, RAS). Gross yield of the Nile tilapia raised in biofloc system differed among several studies; the gross yields ranged from 7.94- 8.49kg/ m^3 **(Ridha *et al*., 2020)** and from 4.03- 4.9kg/ m^3 **(Widanarni *et al*., 2012; Mansour & Esteban, 2017)**.

The higher protein efficiency ratios and the better FCR values obtained in the 1.4% feeding rate treatment (Table 2) indicated the possibility of using restricted feeding when the Nile tilapia are reared in biofloc culture. This indicated higher efficiency and profitability of the restricted feed input where juvenile tilapia can obtain supplementary nutrition from feeding on suspended biofloc material in tank water. The lack statistical differences in daily biomass gain among treatments can be ascribed to the good abundance of biofloc material rich in protein (30% crude protein) according to **Ballester *et al.* (2010)**. The lowest biomass gain/m^3/day obtained in the 60% feed input treatment (*P*<0.05) indicates that a higher feeding rate should be adopted in order to obtain economic growth.

Table 2. Growth and feed efficiency of Nile tilapia reared at different feeding rates during the fattening stage using biofloc technology

Parameter	Feeding rates			
	control	**1.6%**	**1.4%**	**1.2%**
Initial weight (g/fish)	109.29±1.02^{ab}	108.66±3.03a^{b}	105.95±0.795^{b}	109.08±4.39^{ab}
Initial weight (g/fish)	273.88±4.18^{b}	258.13±5.50^{b}	264.99±25.73^{b}	223.55±9.15^{c}
Weight gain (g/fish)	164.59±5.20^{b}	149.47±8.54^{b}	159.04±24.94^{b}	114.47±4.77^{c}
Daily weight gain (g/fish/day)	1.35±0.04^{b}	1.22±0.07^{b}	1.30±0.205^{b}	0.936±0.04^{c}
SGR (% / day)	0.750±0.02^{b}	0.710±0.04^{b}	0.746±0.075^{b}	0.590±0.0^{c}
Final biomass harvest/tank (kg fish/tank)	8216.5±125.5^{b}	7867.5±219.5^{b}	8356±943.0^{b}	6356±299.0^{c}
Final biomass harvest/m^3 (kg fish/m^3)	4108.25±62.75^{b}	3933.75±109.75^{b}	4178.0±471.5^{b}	3178.0±149.5^{c}
Initial biomass harvest/tank (kg fish/tank)	3551.50±21.50^{a}	3477.0±97.0^{ab}	3390.5±25.5^{b}	3490.5±140.5^{ab}
Initial biomass harvest/m^3 (kg fish/m^3)	1775.75±10.75^{a}	1738.5±48.5^{ab}	1695.25±12.75^{b}	1745.25±70.25^{ab}
Biomass gain/tank (kg fish/tank)	4665.0±104.0^{b}	4390.5±122.5^{b}	4965.5±917.5^{b}	2865.5±439.5^{c}
Biomass gain/m^3 (kg fish/m^3)	2332.5±52.0^{b}	2195.25±61.25^{b}	2482.75±458.75^{b}	1432.75±219.75^{c}
PER	1.37±0.07^{c}	1.70±0.005^{b}	2.13±0.20^{a}	1.57±0.270b^{c}
FCR	2.43±0.125^{a}	1.96±0.01b^{c}	1.57±0.151^{d}	2.15±0.376^{ab}
Survival (%)	92.33±1.45^{ab}	95.3±4.7^{ab}	98.43±1.55^{a}	89.1±7.8^{b}

Means in the same row with different letters are significantly different (*P*<0.05)

3. Survival rate of experimental fish

Survival of Nile tilapia in all biofloc treatments showed significant improvement ($P<0.05$) which ranged between 89.1 and 98.4% (Table 2). **Emerenciano (2012)** indicated that growth and health of cultured organisms were improved when reared in biofloc medium. This may be due to the supplemental biofloc nutrition for the Nile tilapia, as well as the availability of abundant natural microbes and bioactive compounds. Biofloc could be considered as a matter rich in growth promoters as well as bioactive compounds that improve health status in cultured organisms **(Singh *et al*., 2005)** and increase digestive enzymes **(Xu & Pan**, **2012)**. The higher survival rate obtained in the current experiment were related to the good water quality of biofloc medium according to **Crab *et al*. (2012)** and **Wasielesky *et al*. (2013)**.

4. Feed efficiency

4.1. Feed conversion ratio (FCR)

When restricted feeding was employed in biofloc tanks, feed efficiency was ameliorated. Both feed conversion and protein efficiency ratios were improved when the Nile tilapia was fed at 70% of the control input (Table 2). **Emerenciano *et al*. (2017)** reported that, biofloc technology supplies tilapia with continuous extra food source 24 hour a day in the form of microorganisms and microbial community, allowing a reduction of FCR **(Luo *et al*., 2017)**. Better FCR reduce production costs **(Correa *et al*., 2020)** due to the reduction in pelletized feed inputs in biofloc tanks. Moreover, **Luo *et al*. (2014)** and **Long *et al*. (2015)** noted that biofloc consumption improves feed efficiency and fish yield.

Feeding the Nile tilapia above 1.4% of biomass resulted in the deterioration of feed efficiency (Table 2). The deterioration in FCR value in the control treatment may be due to the adverse effect of its high feed inputs, compared to the restricted feed. Crude protein of biofloc matter had a range of 17-30% on dry matter basis **(Luo *et al*., 2014)**, which is appropriate for the Nile tilapia, improving feed conversion and growth rate, and resulting more efficient utilization of dietary inputs **(Widanarhi *et al*., 2012)**.

Rakocy *et al*. (2004) obtained FCR of 1.9-2.2 in biofloc system during the fattening stage of tilapia with ad libitum feeding. Several studies reported FCR range of 1.72-1.8:1 when the Nile tilapia fish were raised in biofloc technology, 1.8:1 **(Rakocy *et al*., 2004)**, 1.72-1.8:1 **(Mansour & Esteban, 2017)** and 1.73-1.85:1 **(Ridha *et al*., 2020)**. **Eid *et al*. (2020)** reported FCR values ranging from 1.62-1.96:1 when the Nile tilapia was cultured under different stoking densities using BFT. **Schwarz *et al*. (2016)** obtained feed conversion range of 1.56-1.78 and survival rate of 92- 94% for the Nile tilapia using BFT.

Feed conversion ratios were improved in the 1.4% and 1.6% feed levels (1.57 and 1.96:1, respectively), compared to the control treatment (2.43:1), which reflected the positive effect of biofloc material as a source of nutrition for the Nile tilapia during the fattening process. **Ogello *et al*. (2014)** revealed that, protein is eaten twice in the form of feed as well as microorganisms in biofloc by filter feeding tilapia, and microbial biomass in this case are considered as supplementary food source **(Hisano *et al*., 2021)**.

Both **Rakocy *et al*. (2004)** and **Manduce *et al*. (2021)** obtained feed conversion close to 2:1 when the Nile tilapia was cultured in BFT. Moreover, feed conversion ratio of tilapia raised in biofloc system ranged from 1.61-1.89:1, with no significant difference among treatments **(Lima *et al*., 2018)**, while the Nile tilapia was cultured in biofloc system during the fattening stage. Biofloc matter contains up to 30% protein and 2% lipids **(Ballester *et al*., 2010; Xu & Pan, 2012; Luo *et al*., 2014)**.

The lower feed consumption in the Nile tilapia raised in BFT was due to the continuous harvest of biofloc material over 24 hours a day as supplemental food source, which resulted in higher feed efficiency **(Ekasari & Maryam, 2012; Haridas *et al*., 2017)**. In this regards, **Perez-Fuentes *et al*. (2016)** reported that, biofloc intake by tilapia contributed to the diet of fish, which resulted in the reduction of daily feed consumption.

4.2. Protein efficiency ratio (PER)

Increasing feeding levels in the control treatment didn't improve PER value which averaged 1.37 during the experimental period. When restricting feeding levels to 1.4-1.6%, the protein efficiency ratios improved to 1.7-2.13 range (Table 2), compared to the control treatment, with significant differences among treatments. Further restriction of the feeding level to 1.2% resulted in a decrease in PER value to 1.57. Consequently, it is recommended to feed the Nile tilapia at a restricted level with 1.4% of biomass compared to the control.

Increasing feeding level above the 1.4% did not improve PER ratio among treatments, indicating better feed management when feeding level was lowered enhancing feed efficiency. Retention of dietary protein is improved in biofloc culture system, which results in high PER efficiency and reduction in feed cost **(Mansour & Esteban, 2017)**. Best protein efficiency of bioflocs is due to high nutritional quality of bioflocs that included bacteria and phytoplankton as well as rotifers, protozoa and copepods **(Ray *et al*., 2018; Hisano *et al*., 2019)**. The deterioration in PER values may be due to the adverse effect of over-feeding.

Utilization of high- quality protein in biofloc matter increased PER ratio of the Nile tilapia compared to non BFT treatment **(Ogello *et al*., 2014)**. PER values were better in the 1.4% restricted treatment than that of the control treatment. The results of the current experiment indicated that the Nile tilapia could be reared under restricted feeding level when reared in biofloc culture, and the amount of feed inputs could be lowered without affecting survival or feed efficiency since biofloc material provide extra nutrition to the filter feeding the Nile tilapia. Furthermore, increasing dietary input in the control treatment did not improve PER value. Consequently, it is recommended that the Nile tilapia should be fed at restricted 1.4% level in order to obtain acceptable growth and economic returns. It is not recommended to feed Nile tilapia at restricted 1.2% level since growth performance was deteriorated.

CONCLUSION

It is concluded that, the Nile tilapia with weight above 100gram/ fish individual should be fed with 1.4% of biomass per day instead of 2% in biofloc supported system since slight variations were detected among dietary treatments. Additional nutrition from suspended biofloc material enabled similar growth performance of the Nile tilapia when fed at 1.4% per day, compared to the higher feeding rate adopted in the control treatment. Fish should not be fed at the lowest feed level with 1.2% of biomass when optimal weight gain is desired under the biofloc treatment. The results showed that there was no need for feeding fish with inputs higher than 1.4% of biomass when feed would be applied in biofloc culture during the fattening stage.

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