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Adaptability of Nile Tilapia (*Oreochromis niloticus*) in Biofloc Systems: Effects on Growth, Feed Efficiency, Water Quality, and Economic Viability

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Abstract

Biofloc Technology (BFT) has emerged as a sustainable and cost-effective solution for aquaculture, addressing critical challenges such as water conservation, feed efficiency, and environmental impact. This study investigates the adaptability of Nile tilapia at different life stages to BFT systems, focusing on growth performance, survival rates, feed conversion ratios (FCR), and economic viability. Three treatments were evaluated: 20-day-old tilapia fry (T1), 35-day-old juvenile tilapia (T2), and 50-day-old adult tilapia (T3), each with three replications. Over a 14-week rearing period, weekly sampling revealed significant differences ($p<0.05$) in growth and survival rates. Juvenile tilapia (T2) demonstrated superior adaptability, achieving the highest final weight gain (292.33 ± 5.54 g), survival rate (98.67 ± 0.58%), and economic return, with the best benefit-cost ratio (BCR: 1.426) and lowest FCR (0.647 ± 0.028). These findings highlight the potential of BFT to enhance sustainable aquaculture practices by improving feed efficiency, reducing operational costs, and increasing profitability for farmers. This study underscores the commercial viability of using juvenile tilapia in BFT systems, offering a scalable and environmentally friendly approach to meet the growing demand for aquaculture production.

INTRODUCTION

In terms of food production, aquaculture has grown at the fastest rate in recent years, although its sustainability is unclear (Custódio *et al.*, 2020; FAO, 2020). Historically aquaculture has solely relied on monoculture, which requires a lot of land, a

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lot of water, and a lot of fishmeal to generate feed to produce a lot of fish. Inappropriate aquaculture waste disposal can have negative consequences on the environment, including the spread of pathogens, contamination of the land and water, and eutrophication of aquatic habitats. These environmental issues are detrimental to aquaculture's ability to remain sustainable (Boyd *et al*., 2020). These problems have been addressed, and biofloc-based systems have been proposed as a way to further aquaculture sustainability.

Aquaculture has emerged as one of the fastest-growing sectors in global food production, yet its sustainability remains a pressing concern (Custódio *et al*., 2020; FAO, 2020). Traditional aquaculture practices, often reliant on monoculture systems, demand significant resources, including land, water, and fishmeal-based feeds, while generating substantial environmental impacts such as nutrient pollution, habitat degradation, and eutrophication (Boyd *et al*., 2020). To address these challenges, Biofloc Technology (BFT) has been proposed as a sustainable alternative, offering benefits such as improved water quality, reduced feed costs, and enhanced nutrient recycling (Khanjani *et al*., 2024). By fostering the growth of heterotrophic microbial communities, BFT systems convert organic waste into protein-rich bioflocs, which serve as a supplementary feed source for cultured species (Avnimelech, 2009; Crab *et al*., 2012).

Tilapia (*Oreochromis niloticus*), a globally popular aquaculture species, is well-suited for BFT systems due to its omnivorous feeding habits, environmental adaptability, and rapid growth rates (FAO, 2016). However, the successful implementation of BFT in tilapia farming requires a deeper understanding of how different life stages—ranging from fry to adults—adapt to biofloc environments. While previous studies have explored BFT's benefits for tilapia culture, critical gaps remain. For instance, limited research has examined how age-specific adaptability influences growth performance, survival rates, and economic viability in BFT systems. Furthermore, existing studies often lack comprehensive evaluations of water quality dynamics, feed efficiency, and cost-benefit analyses, particularly for juvenile and adult tilapia. Nevertheless, no published data on the impact of the adaptation ability of various aged Tilapia fish on water quality, growth performance, survival rate, and economic viability with the use of Biofloc Technology is currently available.

This study hypothesizes that juvenile tilapia (35 days old) will exhibit superior adaptability in BFT systems compared to fry (20 days old) and adult fish (50 days old), achieving higher growth rates, better feed conversion ratios (FCR), and greater survival rates. By focusing on age as a key variable, this research aims to address a critical gap in the literature, providing insights into the optimal life stage for BFT implementation. Additionally, the study evaluates the economic viability of BFT for tilapia farming, offering practical recommendations for sustainable and cost-effective aquaculture practices.

The objective of the current study was to evaluate the adaptability of Nile tilapia fish of various ages and weights and to ascertain growth performance and survival rates when cultured in indoor tanks using biofloc technology (BFT).

METHODOLOGY

Ethical Approval

All procedures involving live animals were conducted in strict adherence to the ARVO Statement for the Use of Animals in Ophthalmic Vision and Research. The ethical principles outlined in the National Institutes of Health Guide for the Care and Use of Laboratory Animals (NIH Publications No. 85-23, revised 2011) were also followed. The research protocols were approved by the Ethics Committee on Animal Use (Protocol No. 06174/14) at FCAV/Unesp, Jaboticabal.

The fish were reared optimally, with only weekly samplings and taking due care to minimize stress. No invasive procedures

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were performed; health status checks on the fish were routine for welfare purposes.

Place and Time

At the BRAC Prawn and Tilapia Hatchery in Dumuria, Khulna, Bangladesh, the experiment was conducted. Fingerlings of Nile tilapia, *Oreochromis niloticus* (GIFT strain), were captured from this hatchery. This experiment was conducted from 28 June 2021 to 6 October 2021 for 98 days, culture period was 90 days.

Research Materials

All the collected fish (n= 900) had different ages and were from different batches. For conducting this research, the following three treatments were run: Treatment 1 (T1) or controlled with 3 replications (n=100): 20 days aged Tilapia fry; Treatment 2 (T2) with 3 replications (n=100): 35 days aged juvenile Tilapia, and Treatment 3 (T3) with 3 replications (n=100): 50 days aged Adult Tilapia.

The selection of 20, 35, and 50 days as treatment groups was based on key developmental stages in tilapia growth, which influence their adaptability to Biofloc Technology (BFT). These age groups represent distinct physiological and metabolic changes: 20-day-old fry (early-stage larvae with high sensitivity to environmental changes), 35-day-old juveniles (intermediate developmental stage where adaptability to BFT conditions can be tested), and 50-day-old adults (more developed fish with a potentially stable physiological response to BFT environments).

While previous studies on tilapia adaptability in BFT are limited, existing research suggests that younger fish exhibit higher plasticity in response to environmental factors. This study aims to investigate whether there is a critical threshold age for tilapia adaptability in BFT.

Research Design

This study was conducted in a tarpaulin pond with a diameter of 3 meters and a height of 1.2 meters. This study was conducted using various types of fish distribution, namely: A) 250 fish/m^3, B) 500 fish/m^3, C) 750 fish/m^3, and D) 1000 fish/m^3. Each treatment was repeated 3 times.

Work Procedure

Tank and Water Preparation

Nine circular cemented indoor tanks (2m^3 or 2000-liter capacity) were prepared through a standardized cleaning and disinfection process. Day 1: Cleaned with 5% HCl, the tanks were left for a full day. Day 2: Cleaned with potassium permanganate solution, followed by a two-day drying period. Day 4: Partially filled with water, treated with bleaching powder (potassium hypochlorite), and aerated.

Water depth was kept between 2 and 2.5 feet for the duration of the trial. Aeration System: Five air stones per tank at different depths, with a 0.50 HP aerator ensuring continuous aeration. Fish Welfare: Expert staff monitored fish health and feeding routines.

Biofloc Preparation

Initial Water Quality Check at DO: 7.6 mg/L, pH: 7.6, Temperature: 29.7°C, Ammonia: 0 ppm, Salinity: 0 ppt, TDS: 0.35 ppm, Iron: 0 ppm. Nutrient Addition in the morning: 1 kg salt, 100 g $CaCO_3$ per tank. Continuous aeration was ensured in every tank. In the evening, 250 g molasses, 25 g Pond Care probiotic (C/N ratio maintained at 10:1).

Biofloc Maturity

After one week, water quality was reassessed (DO: 5.8 mg/L, pH: 8.3, Temperature: 29°C, Ammonia: 0 ppm, Salinity: 1 ppt, TDS: 900 ppm). Fish stocking occurred once biofloc stability was achieved (approximately 8 days after initiation). Before stocking, fish underwent a one-week conditioning period, including a 10-minute disinfection bath with 10 ppm salt solution.

Biofloc development and stability were monitored through both water quality

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parameters and microbial composition indicators. Microbial Composition: Although direct bacterial strain identification was not conducted, biofloc stability was inferred using the following : total heterotrophic bacteria (THB) count (colony-forming units per mL), water turbidity measurements as an indirect indicator of microbial balance. Nitrogen cycle efficiency is inferred from ammonia, nitrite, and nitrate levels. Biofloc stability was maintained through a 10:1 carbon-to-nitrogen (C/N) ratio using molasses and probiotic applications.

Feeding Strategy

Fish were fed at 1-2% of biomass daily, based on previous research on feeding protocols for tilapia in BFT systems. In traditional tilapia culture, FCR typically ranges from 1.5 to 2.0, whereas in biofloc systems, it can be reduced to 1.0 - 1.4 due to microbial protein utilization and improved water quality management (Avnimelech, 2009; Emerenciano *et al.*, 2012). This rate was selected to optimize feed conversion while minimizing excessive organic load in biofloc systems.

Feed Types: Commercially available floating feed from Quality Feeds Limited. Starter Feed Composition: Crude Protein (Min)- 30%, Fat (Min)- 6%, CHO (Max)- 22%, Fiber (Max)- 3%, Ash (Max)- 12%, Calcium (Max)- 2%, Pho (Min) -1%). Grower Feed Composition: (Moisture (Max)-10%, Crude Protein (Min)- 26%, Fat (Min)- 5.6%, CHO (Max)- 22%, Fiber (Max)- 3.2%, Ash (Max)- 10%, Calcium (Max)- 1.9%, Pho (Min) -1%). Uneaten feed and feces contributed to biofloc development, ensuring efficient resource use.

Water quality parameter

Water quality was monitored weekly, ensuring that ambient parameters such as water temperature, pH, dissolved oxygen (DO), Salinity, Ammonia, and TDS. About 10% of the water was exchanged once in two weeks to minimize ammonia. After the water was exchanged, the floc volume was measured in the evening. Instead of measuring the floc using an Imhof cone, we utilized a 1-L local plastic bottle. The bottle was filled with water from the tank, allowed to sit for thirty minutes, and then examined using the spotted scale that the floc had left behind. Probiotics and molasses were added during the study period when the water was exchanged under the criteria to maintain the 10:1 C/N ratio.

Data Analysis

The growth performance indicators—including weight, specific growth rate (SGR), and feed conversion ratio (FCR)—along with survival rates, were recorded at seven-day intervals post-stocking. A 10% sample size was used for data collection, and a digital precision scale was utilized to weigh the experimental fish. No anesthetics were applied during the sampling process.

One-way analysis of variance (ANOVA) at an accuracy level of 95% was used for evaluating the mean values of growth parameters, survival, FCR, and water quality for each treatment. To investigate the comparison between mean values of each treatment, Tukey's HSD was used by Zar's (1996) methodology. All tests were conducted at the 5% significance level. Microsoft Excel (Microsoft Office Premium 13) and the SPSS Windows v.27.0 program (SPSS, Chicago, Illinois, USA) were used for all statistical analyses. The mean±standard deviation (S.D.) was used to express all data.

The percent weight gain, specific growth rate (SGR %), survival rate (%), and feed conversion ratio (FCR %) were determined using the following formulas (Roy *et al.*, 2020):

Survival (%) = (Number of fish survived/number of fish stocked) ×100

Specific growth rate (% day^{-1}) = ((ln final weight−ln initial weight)/duration in days) ×100

Percent weight gain (%) = ((Mean fish final weight−Mean fish Initial weight)/ rearing periods (total period)) × 100

FCR = (Weight of consumed feed/weight of produced fish)

The economic feasibility of Asian

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Seabass aquaculture was evaluated based on the methodology of Kumaran *et al*. (2021), using calculations of the payback period and benefit-cost ratio.

PBP = Initial Investment/Annual cash inflow (ACF)

BC Ratio = (DCFb/DCFc) (Discounted value of benefit (DCFb) and discount value of cost (DCFc))

RESULTS AND DISCUSSIONS

Effects of BFT on growth performance: Body Weight

To determine the adaptability of Tilapia in a BFT-based culture system, different weights of fish were utilized in the analysis of the influence of BFT on the growth of Tilapia fish, and the findings are shown in Table I. According to the study, Tilapia fish treated with T2 gained more weight and had the highest SGR and PWG than fish treated with T3 and T1 under BFT. Besides that, the survival rate of tilapia in the T2 treatment was highest. Table 1 shows that the T2 treatment had the highest survival rate.

Fourteen sampling sessions were conducted throughout the research period. The first sampling recorded the lowest weight gain, as the experimental fish required time to acclimate to the new culture environment. From the second sampling onward, weight gain began to increase. Between the third and seventh samplings, the highest and most stable growth rates were observed, with T2 exhibiting the greatest weight gain due to favorable environmental conditions, physiological adaptation, and the gestation period.

After the eighth sampling, weight gain slowed across all experimental fish, as growth naturally declined after a certain age. Among the three treatments, 35-day-old Tilapia in the T2 group achieved the highest average weight gain. The SGR, a key metric for assessing aquatic organism growth under experimental conditions, was highest in T2 (2.669±0.018b). As shown in Table 1, fish in the T1 treatment group had the highest survival rate among all treatments.

It has been suggested that their greatest degree of environmental adaptation accelerated their speed of growth and survival. The 35-day-old fish (T2) possessed a transitional history, having been reared in pond water until 35 days old, which seemed to allow them to gradually acclimate to the biofloc system.

In contrast, the older fish (T3) exhibited signs of stress, such as impaired swimming and reduced feeding activity, presumably as a result of the stressful environment (darkness, increased biofloc volume, and oxygen fluctuation). They were also unable to adapt to the quality of the meal. They could eat both commercial and natural food in the pond. Given their small size and susceptibility to stress, the 20-day-old fish fry is particularly vulnerable to the biofloc environment. Their ability to grow and consume feed was hindered by these.

Observations indicated that certain 20-day-old fry could have been more vulnerable to cannibalistic attack, a stress response to high-density or poor rearing conditions, which explained their lower survival.

Findings from previous studies on other species align with the conclusions of this research. The 20-day-old fry, while having been exposed to biofloc microbial populations at an early stage, have underdeveloped digestive systems. Their higher metabolic rate and susceptibility to environmental stress (including potential cannibalism owing to size and stress-related behavior) may have limited their growth and survival (Emerenciano *et al*., 2011).

The 50-day-old fish, although possessing a mature digestive system, appeared to have issues with the darker, more restricted biofloc environment. This could be due to their reduced tolerance for oxygen changes and the challenge of adapting to high suspended solids, which could have impacted swimming behavior and feed intake (Rakocy *et al*., 2004). Shrimp and fish that consume biofloc benefit from enhanced growth rates, reduced feed conversion ratios (FCRs), and lower feed costs (Avnimelech, 2015).

Key traits for optimal growth in BFT

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systems include the ability to tolerate moderate dissolved oxygen levels (3–6 mg/L), adapt to suspended solids in water (10–15 mL/L of biofloc volume, as measured in Imhoff cones) (Taw, 2010), possess filtering structures (such as those found in tilapia), exhibit omnivorous feeding habits, and have a digestive system capable of efficiently assimilating microbial particles.

Extensive research on BFT-based *Oreochromis niloticus* (tilapia) farming suggests that this approach could yield up to 155 tons per hectare (Rakocy *et al*., 2004). High yields have been observed, along with a loss in FCR and decreased protein in diets. Avnimelech *et al*. (1994) claim that tilapia consume their feed 20% more effectively in a BFT system than they do in a conventional water exchange system. According to a source (Azim and Little, 2008) who researched the effects of BFT on juvenile tilapia, there was no difference in fish growth or production between tanks that fed their fish at 35% and 24% CP while using BFT, even though both were higher than tanks that fed their fish at 35% CP in clear water without biofloc.

There were significant differences ($P<0.05$) among the three treatments in terms of all growth parameters. As a result, 35 days aged juvenile Tilapia fish (T2) resulted in the highest percentage weight gain, specific growth rate, and survival rate. In a nutshell, the current study concluded that the age of fish had a direct effect on the development and survival capacity when cultured in BFT. The lowest FCR was found in T2.

Influence of Biofloc Microbial Populations on Digestion in Different Age Groups

Biofloc microbial communities play a crucial role in digestion and nutrient assimilation in tilapia, particularly in younger fish with developing gut microbiota. Studies suggest that biofloc systems are rich in probiotics, such as Bacillus spp. and Lactobacillus spp., which enhance digestive enzyme activity, improve gut morphology, and increase nutrient absorption efficiency (Avnimelech, 2009). Younger tilapia (20-day-old fry) rely more on external microbial supplementation due to their still-developing digestive systems. The presence of biofloc-associated microbes may provide an advantage by improving digestion efficiency, reducing intestinal stress, and supporting immune functions (Crab *et al*., 2007).

In contrast, older tilapia (50-day-old fish) have a more established gut microbiome, allowing for better endogenous enzyme production and improved feed conversion efficiency. However, their reliance on biofloc microbes for digestion may be lower than that of younger fish, as their gut bacteria are already adapted to breaking down feed components efficiently (Hargreaves, 2013). This suggests that microbial colonization and digestion patterns vary with age, influencing how each age group benefits from biofloc technology.

Nutrient Assimilation Rates Across Age Groups

Nutrient assimilation rates in tilapia are influenced by factors such as metabolic demands, enzyme activity, and gut microbiota composition. Younger tilapia typically exhibit higher protein requirements and faster metabolic rates, which affect their ability to assimilate biofloc nutrients effectively (Emerenciano *et al*., 2012). Biofloc provides a rich source of microbial protein and polysaccharides, which can supplement their dietary needs. However, younger fish may experience lower assimilation efficiency compared to older fish, as their digestive systems are still developing.

Older tilapia (50-day-old juveniles) demonstrate better nutrient retention due to their more efficient digestive processes. Their ability to break down biofloc components, including bacterial protein and organic matter, contributes to improved feed conversion ratios (FCR) and overall growth performance (Megahed, 2010). Comparative studies indicate that while younger tilapia

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can benefit from biofloc as a supplementary feed source, older tilapia may utilize it more efficiently, leading to better economic outcomes.

Effects of BFT on FCR of Tilapia

The feed conversion ratios for the T1, T2, and T3 treatments are mentioned in Table 1. During the trial for increasing 1 kg, Tilapia fish in the T2 treatment showed the best growth rate in terms of FCR.

The Feed Conversion Ratio (FCR) is the basic measurement of the feed required to develop one kilogram of fish. Higher efficiency is indicated by lower FCR values. It is significant to the aquaculture industry. Because a farmer can estimate the amount of feed required, they can calculate the profitability of an aquaculture business. To grow one kilogram of fish, 35 days aged fish of T2 treatment needs 0.647±0.028 kilograms of feed, which was the significantly lowest ($p < 0.05$) amount among all treatments.

Previous studies have demonstrated that biofloc technology enhances feed efficiency by providing an additional nutrient source from microbial aggregates, leading to better growth performance and lower feed costs (Crab *et al*., 2007). Biofloc particles, rich in proteins, lipids, and essential amino acids, contribute to improving feed utilization, reducing feed waste, and lowering dependence on formulated feeds (Megahed, 2010). Studies suggest that tilapia fed on biofloc-based diets exhibit improved weight gain, higher survival rates, and better immune response compared to those in traditional aquaculture systems (Emerenciano *et al*., 2012; Hargreaves, 2013).

The fundamental concept of Biofloc technology revolves around recycling waste nutrients, particularly nitrogen, into microbial biomass. This biomass can either be directly consumed by cultured animals or processed into feed components (Avnimelech, 2009). Reported feed conversion ratio (FCR) values for tilapia vary significantly, ranging from 1.0 to 1.71 in cage culture and 1.5 to 2.5 in pond systems (Rana and Hassan, 2013). Additionally, biofloc serves as a nutrient-rich, protein-lipid natural food source, continuously available within the system due to the complex interactions between organic matter, physical substrates, and diverse microbial communities (Avnimelech, 2015).

A slight increase in FCR could significantly raise the variable cost where feed prices are high. As a result, poor FCR performance has a significant impact on aquaculture's profitability. So, BFT is a blessing to aquaculture farmers to minimize their cost of purchasing feed and it helps to increase the profit.

Effects of BFT on water quality parameters

The water quality indicators stayed within the species-specific ranges. During the research, the meaning of several parameters was assessed and displayed in Table 2.

Water quality control is crucial in aquaculture, as farmed fish are highly sensitive to variations in factors such as toxic chemicals, pH, temperature, and gas levels. To ensure optimal health, growth, and production, water quality must be continuously monitored and effectively managed.

The regular replacement of the pond water with new, clean water from the water supply has been the method most usually utilized to counteract this contamination (Gutierrez-Wing and Malone, 2006). According to Avnimelech (2015), BFT helps to maintain the quality of the water by absorbing nitrogen compounds and producing in situ microbial protein. This organic production is crucial for maintaining the water's purity and recycling nutrients. In aquaculture, organic matter and nitrogen waste are major issues. A high carbon-to-nitrogen ratio (12-20:1) in water is a crucial component in promoting and stabilizing the heterotrophic community in BFT at the start of the culture period.

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Economic analysis of BFT

Economic analysis of the biofloc of Tilapia shown in Table 3 indicated that BCR was highest at 1.426 in T2 treatment and the payback period was 1.14 in T2 which was lowest among the three treatments.

The total fixed cost for establishing the culture system included expenses for tank preparation and accessories such as air pumps, air stones, sampling nets, ropes, pipes, feeding buckets, etc., along with transportation costs. Seed, feed, depreciation on fixed costs, and miscellaneous items were included in operational expenses. Depreciation was calculated based on the fixed costs of the tanks and accessories, which were expected to last for 40 cycles (10 years * 4 cycles per year). Each cycle took 3 months to complete, so fishers could earn income without having to wait a full year.

The payback period (PBP) measures the profitability and liquidity of a business or farm, indicating how long it takes for the investment capital to be returned (Hajdasiński, 1993). In this study, the shortest payback period for the biofloc fish farming business was 1.14 years, meaning the investment capital would be returned after just 5 crop cycles using 35-day-old Tilapia in T2. This suggests the business would start generating income after the second crop. In contrast, T3 would begin earning after the ninth crop, while T1 would start seeing returns after the fifth crop.

The feed conversion ratio (FCR) and benefit-cost ratio (BCR) are impacted by the variation in growth and survival rates caused by the ability of various age groups of tilapia fish to adapt to biofloc technology. The culture of 35-day-old tilapia in biofloc was shown to be an economically viable production method by the culture system's highest BCR and lowest payback period overall. Even when economic indicators show high profitability, it is important to consider the volatility of input and output market prices when interpreting these higher profitability indicator numbers. During the experiment, no disease risks w.ere identified.

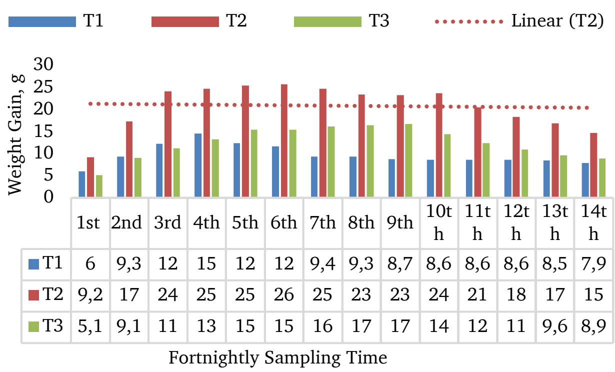

Figure 1. Effects of BFT on weight gain, g of Tilapia fish.

Table. 1. Effects of BFT on the growth performance of Tilapia fish.

Treatment	T1	T2	T3	Effect size metrics, η^2
Avg. Initial Weight, g	16.2 ± 0.265^{c}	29.1 ± 0.917^{b}	44.0 ± 1.682^{a}	0.9946
Avg. Final Weight, g	152 ± 2.138^{c}	321.433 ± 6.352^{b}	219.133 ± 6.438^{a}	0.996
Final Weight gain, g	135.8 ± 2.402^{c}	292.333 ± 5.537^{b}	175.13 ± 6.658^{a}	0.996
Percent weight gain	150.889 ± 2.669^{c}	324.815 ± 6.153^{b}	194.593 ± 7.397^{a}	0.996
SGR	2.488 ± 0.0338^{c}	2.669 ± 0.018^{b}	1.784 ± 0.0539^{a}	0.993
Survival rate	96.67 ± 0.577^{c}	98.67 ± 0.577^{b}	93.67 ± 0.577^{a}	0.95
FCR	0.812 ± 0.039^{c}	0.647 ± 0.028^{b}	1.159 ± 0.059^{a}	0.972

Mean values (mean ± SD) in same row with different superscripts differ significantly ($P<0.05$).

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A one-way ANOVA indicated significant treatment effects on all growth parameters ($\eta^2 > 0.99$), suggesting strong practical differences. Levene's test ($p > 0.05$) confirmed variance homogeneity. Tukey's HSD ($p > 0.05$) found no significant pairwise differences, despite overall ANOVA trends. Effect sizes ($\eta^2 \approx 1$) indicate that treatment had a substantial influence on growth performance. These results suggest T2 as the most effective treatment for maximizing growth and feed efficiency.

Table 2. Water quality parameters in the whole culture period of Tilapia under BFT.

Treatment	T1	T2	T3	Effect size metrics, η^2
pH	5.079±0.727[a]	5.336±0.546[a]	5.614±0.453[a]	0.047
DO	5.079±0.727[a]	5.336±0.546[a]	5.614±0.454[a]	0.13
Ammonia	0.750±0.643[a]	0.357±0.306[ab]	0.25±0.325[b]	0.196
TDS	786.429±116.527[b]	846.429±100.66[ab]	892.143±75.26[a]	0.238
Temperature	29.071±0.616[a]	29.071±0.616[a]	29.071±0.616[a]	0

Mean values (mean ± SD) in the same row with different superscripts differ significantly ($P<0.05$).

Levene's test ($p > 0.05$) confirmed variance homogeneity, validating ANOVA assumptions. Tukey's HSD ($p > 0.05$) found no significant pairwise differences, despite overall ANOVA trends. A one-way ANOVA showed no significant treatment effects on pH ($\eta^2 = 0.047$) and DO ($\eta^2 = 0.13$). Ammonia ($\eta^2 = 0.196$) and TDS ($\eta^2 = 0.238$) showed moderate effects, with T3 having the lowest ammonia and highest TDS levels. Temperature remained constant ($\eta^2 = 0$). Effect sizes (η^2) suggest practical differences, particularly in ammonia and TDS levels.

These results indicate minimal statistical differences between treatments, though T3 showed potential improvements in ammonia reduction.

Table 3. Economic analysis of BFT.

Sl. No.	Module details	Unit & details	T1 Treatment	T2 Treatment	T3 Treatment
1.	Fixed investments				
	1. Tank preparation	USD. Lumpsum	100.00 $	100.00 $	100.00 $
	2. Accessories (Air pump, air stone, sampling net, ropes, pipe, feeding bucket, etc. including transport)	USD. Lumpsum	50.00 $	50.00 $	50.00 $
	3. Total fixed cost	USD	150.00 $	150.00 $	150.00 $
	4. Depreciation	Fixed cost in case of tanks and for other accessories items long for 40 cycles (10 crops *4 cycle per year)	3.75 $	3.75 $	3.75 $
2.	Operational Expenses				
	5. Price of Tilapia	USD	3.00 $	12.00 $	18.00 $
	6. Feed cost	USD	17.60 $	30.80 $	31.35 $
	7. Other cost (Probiotics, CaCo3/ Lime, Molasis, Salt, Labor, Electricity)	USD	16.21 $	16.21 $	16.21 $
	Total operation expenditure	USD	36.81 $	59.01 $	65.56 $
3.	Total expenditure (total	USD	40.56 $	62.76 $	69.31 $

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	fixed cost + total operational cost)				
4.	Income and profitability				
	8. Total production	Kg	44.00	95.17	61.58
	9. Gross income	USD	44.00 $	152.28 $	80.06 $
	10. BCR		0.085	1.426	0.155
	11. Payback Period	Year	3.73	1.14	24. $

Sensitivity Analysis

The two tables below summarize the impact of a 10% increase in feed costs and an increase in Stocking Density on total expenditure, BCR, and payback period.

Table 4. Impact of a 10% Feed Price Increase on Economic Viability.

Treatment	Original Feed Cost ($)	Revised Feed Cost (+10%) ($)	Original Total Expenditure ($)	Revised Total Expenditure ($)	Original BCR	Estimated Revised BCR	Original Payback Period (Years)	Estimated Revised Payback Period (Years)
T1	17.60	19.36	40.56	42.32	↓	↓	-	-
T2	30.80	33.88	62.76	65.84	1.426	~1.38	1.14	~1.2
T3	31.35	34.49	69.31	72.45	↓	↓	-	-

Table 5. Impact of Stocking Density on Economic Viability.

Stocking Density	Feed Cost ($)	Total Expenditure ($)	Revenue ($) (Estimated Increase)	BCR	Payback Period (Years)
Low (T1 - Control)	17.60	40.56	Lower	↓	Longer
Medium (T2 - Optimal)	30.80	62.76	Baseline Revenue	1.426	1.14 (Baseline)
High (+20% More Fish)	~37.00	~72.00	Increased Revenue (~+15%)	~1.50	~1.05
Very High (+40% More Fish)	~44.00	~82.00	Higher Revenue (~+25%)	~1.45	~1.08

Key Findings

BCR decreases proportionally as costs rise. For T2, BCR drops from 1.426 to ~1.35, meaning a lower profitability margin. Higher feed costs reduce the economic advantage of Biofloc Technology (BFT), making cost-efficiency even more critical. A longer payback period means the investment takes more time to recover.

Higher stocking density improves BCR and shortens the payback period because more fish are produced, leading to increased revenue. However, very high stocking densities may lead to diminishing returns due to competition for resources, stress, and potential survival rate. Optimal stocking density (T2) balances growth efficiency, feed cost, and economic return.

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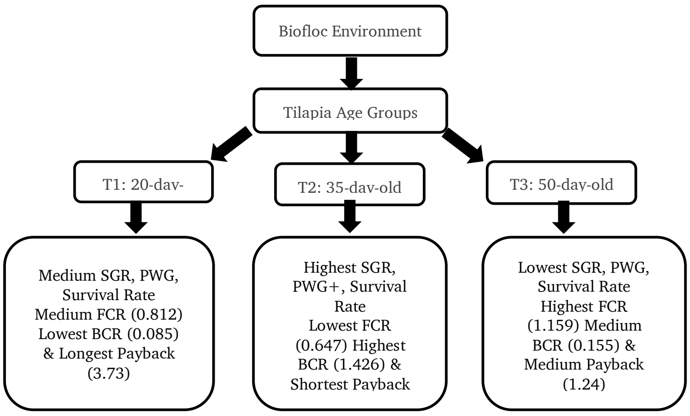

Figure 2. A flow diagram summarizing key findings.

CONCLUSION

Biofloc Technology (BFT) offers superior benefits for aquaculture through enhanced water quality, nutrient recycling, and feed efficiency. This study demonstrated that 35-day-old tilapia exhibited the best growth performance, feed conversion ratio (FCR), and economic viability and therefore are the most suitable choice for BFT systems. Based on these findings, farmers should implement stocking tilapia at this age as a standard practice, and the optimal stocking density should be 300–400 fish/m^3 to maximize productivity and profitability.

Also critical is attaining the best 15:1 to 20:1 carbon-to-nitrogen (C: N) ratio in stabilizing microbial communities in bioflocs. A 15:1 to 20:1 ratio is critical as it promotes optimal nutrient assimilation, supports beneficial bacterial growth, and minimizes waste nitrogenous accretion.

Future research should emphasize microbial profiling in BFT systems for maximizing digestion and feed conversion among various age classes. Moreover, assessing the impact of alternative carbon sources, different stocking densities other than 300 fish/m^3, and long-term economic viability will give a better understanding of enhancing BFT applications for tilapia and other aquaculture species.

CONFLICT OF INTEREST

The authors declare that they have no known financial conflicts of interest or personal relationships that could have influenced the work presented in this paper.

AUTHOR CONTRIBUTION

The author's contribution contains an explanation of the contribution each author provides to the study/experiment. Farhana Islam Shawon: Conceptualization; Data curation; Investigation; Methodology; Project administration; Software; Supervision; Validation; Visualization. MD. Najmul Islam: Formal analysis; Software; Validation; Writing - review & editing. Ferdous Islam: Formal analysis; Roles/Writing - original draft; Writing - review & editing. MD. Hosne Azam: Conceptualization; Funding acquisition; Investigation; Project administration; Resources; Supervision; Validation.

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