Bioscientist: Jurnal Ilmiah Biologi
https://e-journal.undikma.ac.id/index.php/bioscientist

March 2026 Vol. 14, No. 1
e-ISSN: 2654-4571
pp. 249-260

The Effects of Different Aquaponic System Designs (NFT and DWC) on Water Quality, Growth, and Survival of Nile Tilapia (*Oreochromis niloticus*)

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Received: February 2026; Revised: March 2026; Accepted: March 2026; Published: March 2026

Abstract: This study aimed to evaluate the effects of different aquaponic system designs, namely Nutrient Film Technique (NFT) and Deep Water Culture (DWC), on water quality, growth, survival rate, and feed efficiency of Nile tilapia (*Oreochromis niloticus*). The experiment was conducted for 30 days in the Wet Laboratory of the Aquaculture Study Program, Faculty of Fisheries, Dharmawangsa University, using a Completely Randomized Design (CRD) with three treatments and three replicates: control (without hydroponics), DWC, and NFT. The observed parameters included absolute weight gain, absolute length gain, specific growth rate (SGR), survival rate (SR), feed conversion ratio (FCR), and water quality (temperature and pH). Data were analyzed using ANOVA at a 95% confidence level ($\alpha = 0.05$). The results showed that differences in aquaponic system design had a significant effect ($P < 0.05$) on the growth and survival of Nile tilapia. The DWC treatment produced the highest absolute weight gain of 8.5 g with a survival rate of 100%, whereas the NFT system resulted in a weight gain of 5.8 g with a survival rate of 80%. The lowest FCR was recorded in the DWC system (1.00), compared with NFT (1.07) and the control (1.25). Water quality remained within the optimal range throughout the study, with temperatures of 26–31°C and pH values of 6.6–7.2. It can be concluded that the DWC system was more effective than the NFT system and the control in improving the growth and survival of Nile tilapia.

Keywords: Aquaponics; deep water culture; nutrient film technique; *Oreochromis niloticus*; fish growth

How to Cite: Lubis, K. A., Siswoyo, B. H., & Afriani, D. T. (2026). The Effects of Different Aquaponic System Designs (NFT and DWC) on Water Quality, Growth, and Survival of Nile Tilapia (Oreochromis niloticus). *Bioscientist: Jurnal Ilmiah Biologi*, *14*(1), 249–260. https://doi.org/10.33394/bioscientist.v14i1.20014

https://doi.org/10.33394/bioscientist.v14i1.20014

INTRODUCTION

The aquaculture sector plays a crucial role in meeting this demand, given its increasing contribution to global fish availability from year to year. Nevertheless, the efficiency and sustainability of aquaponic systems are largely determined by their construction design, particularly the hydroponic unit. In general, two construction types are commonly applied: Deep Water Culture (DWC) and Nutrient Film Technique (NFT). Each method has its own advantages and limitations in supporting both fish and plant growth. In the DWC system, plants are placed on rafts floating on nutrient-rich water at a certain depth, allowing the roots to remain submerged and to experience relatively stable temperature and moisture conditions (Somerville et al., 2014). In contrast, the Nutrient Film Technique (NFT) system applies a thin layer of nutrient-rich water that continuously flows through plant roots within channels. This method provides an adequate oxygen supply to the roots, but it tends to be more sensitive to flow instability and the risk of clogging (Rakocy, 2012).

Aquaponics is a method that integrates fish culture with hydroponic techniques, in which metabolic waste and uneaten fish feed are utilized as nutrient sources for plants. As a result, it creates an integrated, efficient, and sustainable system (Atuhuta, 2024). This process involves the crucial role of nitrifying microorganisms, which convert ammonia (NH_3/NH_4^+) into nitrite (NO_2^-), and subsequently into nitrate (NO_3^-), which can be absorbed by plants as a nitrogen source. Through this mechanism, plants help maintain water quality by absorbing excess nutrients, while fish provide a natural nutrient source that supports plant growth (Maucieri et al., 2018). This symbiotic principle makes aquaponics an efficient food production system in terms of water use, one that generates minimal waste and has strong potential for development in areas with limited land and water resources (Somerville et al., 2014).

Tilapia (Oreochromis niloticus) is one of the freshwater fish commodities with high economic value and considerable potential for aquaculture development. This species has high market acceptance and is widely favored by consumers, resulting in continuously increasing demand (Siregar et al., 2024). In addition, tilapia is known for its strong adaptability to various environmental conditions, including fluctuations in water quality (Hutabarat et al., 2024). Other advantages include relatively rapid growth and efficient feed conversion, making it one of the most suitable and frequently used species in aquaponic systems (Yavuzcan Yildiz et al., 2017). With the increasing consumption of tilapia, sustainable and well-planned aquaculture practices are needed to ensure production continuity and meet market demand (Manullang, 2020).

Several previous studies have shown that variations in aquaponic system construction design can affect water quality, nutrient absorption efficiency, and the growth performance of fish and plants. For example, Shobihah et al. (2022) reported that system design influences fish productivity across different aquaponic construction types, while Al-Zahrani et al. (2023) found that fish stocking density in NFT systems affects growth rate and feed conversion efficiency. However, studies directly comparing NFT and DWC systems for tilapia (Oreochromis niloticus), particularly under tropical climatic conditions such as those in Indonesia, remain limited. Therefore, this study is important to evaluate the effects of different aquaponic system constructions on water quality, growth, and survival of tilapia, thereby providing a basis for implementing more efficient and sustainable aquaponic systems. The objectives of this study were to determine the differences in aquaponic system construction with respect to water quality parameters during tilapia (Oreochromis niloticus) culture, to examine the effects of different aquaponic systems on the growth and survival of tilapia, and to identify the aquaponic system that provides the best performance for tilapia culture based on fish growth and water quality indicators.

METHOD

Study Location and Period

This study was conducted for approximately one month, from January to February 2026, at the Wet Laboratory of the Aquaculture Study Program, Faculty of Fisheries, Dharmawangsa University.

Equipment and Materials

The equipment used in this study included 30-L buckets, a KD-PSP-2200 submersible aquarium water pump, 2-inch hydroponic pipes (1 m in length), ½-inch PVC pipes (1 m in length), ½-inch PVC pipes (100 cm in length), ½-inch elbows, ½-inch Rucika T-connectors, a pH meter, a dissolved oxygen (DO) meter, a digital balance, and other supporting tools required for the experiment. The materials used included Nile tilapia fingerlings, Malang sand, rockwool, water, water spinach seedlings, commercial feed, and other supporting materials necessary for the study.

Experimental Design

The study employed a Completely Randomized Design (CRD) consisting of three treatments and three replicates, resulting in a total of nine experimental units. The treatments tested as independent variables were as follows:

P0 = Control without hydroponics
P1 = Deep Water Culture (DWC) aquaponic system
P2 = Nutrient Film Technique (NFT) aquaponic system

The dependent variables included growth, survival rate (SR), and feed conversion ratio (FCR). The controlled variables maintained constant throughout the experiment included stocking density, water volume, feed, and temperature.

Work Procedure

1. Preparation stage

The preparatory stage began with setting up the wet laboratory, including cleaning the research area, ensuring the availability of water and electricity, preparing tables or racks for the experimental containers, providing adequate lighting, and installing an electrical system protected from water splashes.

Equipment and materials were then prepared by collecting all research necessities, washing and cleaning the containers, pipes, and other equipment, and disinfecting the containers using a 10 ppm potassium permanganate solution for 24 h. After disinfection, the equipment was dried under sunlight. Measuring instruments, including the pH meter, DO meter, and digital balance, were calibrated, while the pump, aerator, and electrical system were tested to ensure that all equipment functioned properly.

2. Construction of the aquaponic system

a. Deep Water Culture (DWC) system setup

The fish-rearing container consisted of a 20-L bucket filled with clean water and left for 24 h to remove chlorine. A submersible pump was installed in the center of the container to maintain water circulation at a flow rate of 2 L/min, allowing the entire water volume to circulate within approximately 20 min.

The DWC hydroponic unit consisted of a hydroponic pipe positioned above the bucket and fitted with five net-pot holes. A circulation bucket was placed beside the fish container, with a net-pot pipe raft containing 10 holes. An aerator with two outlets was installed. The total effective volume of the system was approximately 40 L, with a fish-to-plant ratio of 1:5 (one fish per five plant net pots).

b. Nutrient Film Technique (NFT) system setup

The preparation of the fish container was the same as for the DWC system, using a 20-L bucket filled with clean water, left for 24 h, and equipped with a centrally installed submersible pump. The NFT channel consisted of a hydroponic pipe with five net-pot holes, installed at a slope of 2–3° to ensure uniform water flow. The circulation pump was adjusted to a flow rate of 2 L/min so that the entire water volume circulated within approximately 20 min.

A circulation bucket was placed beside the fish container and equipped with 10 holes for water distribution. The NFT system did not require an additional aerator because the thin water film already provided sufficient oxygenation. The total effective system volume was approximately 40 L, with a fish-to-plant ratio of 1:5. Before use, the system was tested for 24 h to check for leaks and ensure smooth water flow.

3. Seedling preparation and planting

a. Seed germination (2 weeks before fish stocking)

Rockwool was cut into cubes measuring 3 × 3 × 3 cm and soaked in clean water for 2 h. Water spinach seeds were then sown in the rockwool and placed in a shaded area. The seedlings were watered with clean water twice daily, transferred to a brighter location after germination, and maintained until they were 14 days old.

b. Transplanting (transfer of seedlings into the system)

Healthy seedlings with uniform growth were selected. The rockwool containing the seedlings was inserted into net pots, and Malang sand was added as a supporting medium. The net pots were then placed into the planting holes. In the DWC system, the roots were ensured to touch the water surface, whereas in the NFT system, the roots were positioned inside the channel.

c. Plant acclimatization in the system

The aquaponic system was operated without fish for 3 days to allow the plants to adapt to hydroponic conditions. Plant growth and health were monitored during this period, and wilted plants were replaced with reserve seedlings. The system was considered ready once the plants appeared fresh and the roots had begun to develop.

4. Fish Preparation

a. Acquisition of Nile tilapia fingerlings

Nile tilapia fingerlings measuring 3–5 cm were obtained from a reliable hatchery. Healthy fish were selected based on active movement, bright coloration, and the absence of wounds. A total of 180 fingerlings were used, consisting of 135 fish for the experiment and 45 fish as reserves. Transportation was carried out in oxygen-filled plastic bags for approximately 45 min.

b. Fish acclimatization

In this procedure, three buckets were used, each containing 60 fish in 15 L of water, resulting in a stocking density of approximately 4 fish/L. This density was considered safe for short-term acclimatization, facilitated water quality control, and reduced stress caused by excessive crowding, in accordance with the recommendation of (Wedemeyer, 1996) in *Physiology of Fish in Intensive Culture Systems*. Using this procedure, the fish were able to adapt safely to the new environment before being transferred to the culture system.

5. Stocking Fish into the Aquaponic System

a. Initial measurements (T0 data)

A total of 30 fish were randomly sampled from the 135 experimental fish. Individual body weight and total length, measured from the tip of the mouth to the end of the tail, were recorded on an observation sheet. The mean initial body weight and length of the population were then calculated.

b. Stocking into the experimental units

Before stocking, the aquaponic system was ensured to be operating stably by measuring water quality parameters, including temperature, pH, and dissolved oxygen (DO). Fish were then gradually introduced into the experimental containers, with each container stocked with 15 fish, resulting in a total of 9 containers × 15 fish = 135 fish. Each container was labeled according to the treatment code to facilitate identification. Fish behavior was observed during the first 2 h to ensure successful adaptation to the new environment, and no feed was provided on the day of stocking. Thereafter, the fish were fed 2–3 times daily at 5% of total biomass, following standard aquaponic culture practices, in order to support optimal growth while preventing feed residue accumulation that could reduce water quality.

6. End of the Experiment and Harvest

a. Final measurements

The fish were fasted for 24 h before final measurement. At the end of the experiment, all fish from each experimental unit were collected, and the number of surviving fish was counted to determine the survival rate (SR). The final total biomass per container was weighed, and the body weight and total length of all surviving fish were measured individually and recorded on the final observation sheet. Fish measurements were conducted once every week for 30 days. Water quality parameters were measured daily at 08:00 and 17:00 Western Indonesian Time (WIB).

b. Final water quality measurements

On the last day of the experiment, all water quality parameters were measured, including temperature, pH, and dissolved oxygen (DO).

Data Analysis

Growth performance and feed conversion data were analyzed using analysis of variance (ANOVA) at a 95% confidence level, with the following hypotheses: H_0, there is no significant difference among treatments (Control, DWC, and NFT), and H_1, there is a significant difference among treatments. Prior to ANOVA, the assumptions of normality and homogeneity of variance were tested using the Shapiro–Wilk test and Levene's test, respectively. When ANOVA indicated a significant difference ($p < 0.05$), Tukey's honestly significant difference (HSD) post hoc test was applied to identify which treatment pairs differed significantly, for example, $p = 0.017$.

Water quality data were analyzed descriptively by calculating the mean and standard deviation for each treatment, comparing the results with the optimal ranges for Nile tilapia, and presenting the data in tables and graphs. In addition, trends in water quality changes from the beginning to the end of the experiment were examined, along with their relationship to fish performance. The formulas for SGR, FCR, and SR are presented below.

1. SGR (Specific Growth Rate)

$$SGR = [(\ln Wt - \ln W_0) / t] \times 100\%$$

Note:
SGR = specific growth rate (% day^{-1})
ln = natural logarithm
t = culture period (days)

2. FCR (Feed Conversion Ratio)

$$\mathrm{FCR} = \frac{\mathrm{F}}{\mathrm{B_t} - \mathrm{B_0}}$$

Note:
F = total feed consumed (g)
B_t = final biomass (g)
B_0 = initial biomass (g)

3. SR (Survival Rate)

$$\mathrm{SR}\ (100\%) = \frac{\mathrm{N\_t}}{\mathrm{N\_0}}\ x\ 100$$

Note:
SR = survival rate (%)
N_t = final number of fish at the end of the culture period (individuals)
N_0 = initial number of fish at the beginning of the culture period (individuals)

RESULTS AND DISCUSSION

Mean Weight Growth of Fish

Differences between the Deep Water Culture (DWC) aquaponic system and the Nutrient Film Technique (NFT) aquaponic system influenced the growth and survival of Nile tilapia juveniles. The results of the measurements and weighing of the mean individual fish weight under each treatment are presented in Table 1.

Table 1. Mean absolute weight growth of nile tilapia under each treatment

Treatment	Initial Length (cm)	Final Length (cm)	Length Growth	
			Absolute (cm)	Relative (%)
Control	2.5	3.6	1.1	44%
NFT	2.5	8.3	5.8	232%
DWC	2.5	11.0	8.5	340%

Based on analysis of variance (ANOVA), the comparison among treatments yielded an F-value of 8.55 with a significance value of 0.017 ($p < 0.05$), indicating that the aquaponic system treatment had a significant effect on fish weight growth. The DWC treatment produced the highest growth compared with NFT and the control. The superior growth observed in the DWC system may be attributed to several factors. The Deep Water Culture (DWC) system allows plant roots to remain continuously submerged in circulating nutrient solution, thereby maintaining relatively stable dissolved oxygen levels and evenly distributed nutrient availability. These conditions support the nitrification process, in which nitrifying bacteria convert ammonia from fish waste into nitrate that can be absorbed by plants, thus improving nutrient-use efficiency. This mechanism also facilitates the removal of excess ammonia and nitrogen compounds, contributing to better water quality for fish (Al-Zahrani et al., 2023; Maucieri et al., 2018). Previous studies have shown that DWC systems can enhance plant and fish growth rates because of optimal nutrient circulation and greater dissolved oxygen stability compared with NFT systems or controls without hydroponics (Al-Zahrani et al., 2023; Maucieri et al., 2018).

Mean Length Growth of Fish

Differences between the Deep Water Culture (DWC) and Nutrient Film Technique (NFT) aquaponic systems also affected the growth and survival of Nile tilapia juveniles in terms of body length. The mean fish length under each treatment is presented in Table 2.

Table 2. Mean absolute length growth of nile tilapia under each treatment

Treatment	Initial Length (cm)	Final Length (cm)	Length Growth	
			Absolute (cm)	Relative (%)
Control	5.3	6.5	^{A}1.2	22.64%
NFT	5.4	9	^{B}3.6	66.66%
DWC	5.4	9	^{B}3.6	66.66%

Based on the results of one-way ANOVA for Nile tilapia length growth, the calculated F-value was 6.30, whereas the F-table value was 5.14 at the 5% significance level. Because the calculated F-value was greater than the F-table value, the aquaponic system treatment had a highly significant effect on Nile tilapia length growth ($p < 0.05$). Furthermore, the Least Significant Difference (LSD) test at the 5% level yielded an LSD value of 0.94. The results indicated that the NFT and DWC treatments did not differ significantly from each other, but both differed significantly from the control treatment. These findings are consistent with previous aquaponic studies showing that improved water quality stability, efficient nutrient recycling, and adequate dissolved oxygen availability can enhance tilapia growth performance compared with non-aquaponic controls. In integrated aquaponic systems, plants and microbial processes help maintain more favorable rearing conditions, which can support somatic growth in fish (Somerville et al., 2014; Yavuzcan Yildiz et al., 2017; Al-Zahrani et al., 2023).

Feed Conversion Ratio (FCR)

The analysis showed that the DWC treatment had the lowest Feed Conversion Ratio (FCR) (1.00), followed by NFT (1.07) and the control (1.25). A lower FCR indicates higher feed efficiency, meaning that the feed provided was more effectively converted into fish weight gain. The mean FCR values for individual fish under each treatment are presented in Table 3.

Table 3. Mean feed conversion ratio (FCR) of nile tilapia under each treatment

Treatment	Replicate	Feed Given (g)	Fish Weight Gain (g)	FCR (Feed/Weight Gain)
Control	1	150	120	1.25
	2	150	110	1.36
	3	150	130	1.15
Mean		150	120	1.25
NFT	1	150	140	1.07
	2	150	135	1.11
	3	150	145	1.03
Mean		150	140	1.07
DWC	1	150	145	1.03
	2	150	150	1.00
	3	150	155	0.97
Mean		150	150	1.00

The high feed efficiency observed in the DWC and NFT treatments may be explained by more stable water quality typically found in aquaponic systems, where plant uptake and microbial nitrification help reduce toxic nitrogenous compounds and maintain conditions favorable for fish metabolism. Adequate dissolved oxygen and reduced environmental stress are known to improve feed utilization, growth performance, and fish welfare in aquaponic systems (Somerville et al., 2014; Wongkiew et al., 2017; Yavuzcan Yildiz et al., 2017). Nutrients derived from fish waste are distributed more evenly, allowing fish to experience more stable water and nutritional conditions. Homogeneous water quality also minimizes stress and disease risk, resulting in lower mortality and more consistent fish growth. The slightly better FCR in DWC likely reflects more stable culture conditions and complete survival, which allowed a greater proportion of the feed input to be converted into harvestable biomass (Yavuzcan Yildiz et al., 2017; Al-Zahrani et al., 2023). Thus, DWC exhibited the best combination of survival, final weight, and feed efficiency, whereas NFT tended to favor higher relative individual growth.

Survival Rate of Nile Tilapia

The survival data of Nile tilapia obtained during the study for each treatment and replicate are presented in Table 4. The data indicate that the survival rate varied among treatments. These differences were presumably associated with water quality, environmental stress levels, and stocking density during the rearing period. In aquaponic systems, particularly under the Deep Water Culture (DWC) and Nutrient Film Technique (NFT) treatments, water quality tended to be more stable because plants absorbed metabolic waste from the fish, thereby reducing the accumulation of toxic compounds such as ammonia. This condition likely reduced fish stress and improved survival (Somerville et al., 2014). In contrast, in the control treatment without an aquaponic system, water quality was relatively less controlled, potentially increasing environmental stress and contributing to higher mortality (Boyd, 2015). Because stocking density was the same across treatments, differences in survival were more likely attributable to rearing environmental conditions than to density itself, with good water quality playing an important role in maintaining fish health and survival (Yavuzcan Yildiz et al., 2017). Accordingly, the superior survival observed in the DWC treatment is consistent with literature indicating that stable aquaponic conditions support fish welfare and overall production performance (Yavuzcan Yildiz et al., 2017; Al-Zahrani et al., 2023). During the study, water quality remained relatively good and homogeneous across treatments, so the fish were not affected by disease and survival remained high.

Table 4. Mortality and survival rate of nile tilapia under each treatment

Treatment	Replicate	Initial Number (fish)	Final Number (fish)	Mortality Number (fish)	Mortality Percentage	Survival (%)
Control	1	15	10	5	50	60
	2	15	9	6	60	60
	3	15	12	3	30	80
Mean					47	66
NFT	1	15	15	0	0	0
	2	15	12	3	30	80
	3	15	15	0	0	0
Mean					1	80
DWC	1	15	15	0	0	100
	2	15	15	0	0	100
	3	15	15	0	0	100
Mean					3.33	100

Based on ANOVA ($p < 0.05$), there was a significant difference among treatments in the survival rate (SR) of Nile tilapia. The DWC treatment showed the highest survival, whereas the control produced the lowest. Post hoc Tukey HSD analysis further indicated that DWC was the best treatment for survival rate and final fish weight. Although NFT showed a high Specific Growth Rate (SGR), the average final fish weight was lower than that of DWC. This was due to the combination of slight mortality in one NFT replicate and fish size distribution: SGR measures the relative growth rate per individual, so high relative growth can still result in lower final biomass when some individuals are lost (Cho & Bureau, 2001; Al-Zahrani et al., 2023).A trade-off analysis between the systems indicated different performance characteristics. DWC was superior in survival and total final weight because of more stable oxygen and nutrient circulation and the use of additional aeration, although the individual SGR was relatively lower. By contrast, NFT showed a higher relative growth rate (SGR), likely because nutrients were absorbed efficiently by plants through the thin flowing film of water; however, slight mortality reduced the average final weight. These findings suggest that the choice of aquaponic system should be aligned with the production objective: DWC is more suitable for maximizing total fish production with high survival, whereas NFT is more appropriate for achieving rapid individual growth despite a slight risk of mortality. Such trade-offs are consistent with aquaponic literature emphasizing that fish performance is shaped by the interaction among water quality, nutrient dynamics, oxygen availability, and management conditions (Yavuzcan Yildiz et al., 2017; Goddek et al., 2015; Al-Zahrani et al., 2023).

Specific Growth Rate (SGR)

Based on the study results, the specific growth rate of Nile tilapia under all treatments and replicates was measured four times during the 30-day rearing period. The daily percentage growth of the fish is presented in Table 5.

Table 5. Specific growth rate (SGR) of nile tilapia under each treatment

Treatment	SGR (%/day)
Control	1.27
DWC	1.33
NFT	1.63

The results showed that the Specific Growth Rate (SGR) of Nile tilapia differed among treatments, with the NFT treatment producing the highest SGR at 1.63%/day, followed by DWC at 1.33%/day, and the control at 1.27%/day. However, this pattern differed from that of absolute weight gain, in which the DWC treatment produced the highest final weight. This difference arises from the nature of the SGR parameter, which measures the relative growth rate in relation to initial body weight, whereas absolute weight growth reflects the absolute increase in biomass. SGR is a relative growth index and generally decreases as fish become larger. Consequently, smaller fish or fish in earlier growth phases may show higher SGR values even when their absolute biomass gain is not the highest (Lorenzo Márquez et al., 2024). Biologically, the higher SGR in NFT may indicate faster relative early growth under continuous water flow and efficient nutrient delivery, whereas the higher final biomass in DWC suggests that greater environmental stability supported more sustained biomass accumulation over time (Somerville et al., 2014; Al-Zahrani et al., 2023). This indicates that SGR is not always directly proportional to absolute weight growth, but is instead influenced by growth dynamics and environmental conditions during rearing.

Comparison of Growth Parameters and Performance of Nile Tilapia Under Each Treatment

A comprehensive comparison of the growth and performance parameters of Nile tilapia under each treatment is presented in Table 6.

Table 6. Comparison of growth parameters and performance of nile tilapia under each treatment

Treatment	Mean Survival Rate (%)	Mean Final Weight (g)	Mean SGR (%/day)	Mean FCR
Control	66	45	1.2	1.25
NFT	93.3	48	1.8	1.07
DWC	100	52	1.5	1.00

Notes:
- Survival Rate (SR): Percentage of fish that survived until the end of the experiment.
- Final Weight: Mean fish weight at the end of the experiment.
- SGR: Specific Growth Rate, or daily relative growth rate.
- FCR: Feed Conversion Ratio, or feed efficiency (total feed ÷ weight gain).

The comparison in Table 6 shows that DWC was superior in survival rate and final weight and also had the best FCR, indicating the highest feed efficiency. In contrast, NFT had the highest SGR, indicating faster relative growth per individual, although slight mortality resulted in a lower average final weight. The control treatment showed the lowest values for almost all parameters, highlighting the clear advantages of aquaponic systems over non-aquaponic culture conditions. This comparison also indicates a trade-off between relative individual growth and total production performance. DWC appears more advantageous when the production target is maximum biomass, survival, and feed efficiency, whereas NFT may be preferable when faster relative individual growth is prioritized (Yavuzcan Yildiz et al., 2017; Goddek et al., 2015; Al-Zahrani et al., 2023).

Water Quality

During the study, the measured water quality parameters indicated that water pH ranged from 6.6 to 7.2, while water temperature ranged from 26 to 31°C. These ranges are still considered optimal for Nile tilapia culture, as reported by Azhari and Tomasoa (2018), who stated that the ideal pH ranges from 6 to 7 and the optimal temperature ranges from 25 to 30°C. Stable water quality is widely recognized as a central determinant of fish growth, feed efficiency, and welfare in aquaponic systems, particularly through the control of dissolved oxygen, ammonia, nitrite, nitrate, temperature, and pH (Somerville et al., 2014; Yavuzcan Yildiz et al., 2017). The relatively optimal temperature conditions observed during the study likely played an important role in supporting fish metabolic processes. Temperature increases within the tolerance range can accelerate metabolic rate, thereby enhancing feed consumption and fish growth. This is consistent with the study results, which showed increased growth under aquaponic treatments, particularly in the DWC and NFT systems. However, excessively high temperatures may also increase oxygen demand and fish stress; therefore, temperature stability remains an important factor in maintaining growth performance and survival.

In addition, water pH within the neutral range tends to support fish physiological conditions and reduce the toxicity of harmful compounds such as ammonia. Under stable pH conditions, the balance between ammonia (NH_3) and ammonium (NH_4^+) is better maintained, thereby reducing the risk of ammonia toxicity. Moreover, nitrogen cycling in aquaponics, especially the conversion of ammonia to nitrate through nitrification, helps reduce toxic ammonia accumulation while supplying nutrients for plant uptake, thereby improving overall system stability (Wongkiew et al., 2017). This likely contributed to the high survival rate observed in the aquaponic treatments, especially in the DWC and NFT systems, which include biological filtration mechanisms through plants. Thus, the relatively stable water quality during the study not only met optimal standards but also directly contributed to improved growth, feed efficiency, and survival of Nile tilapia. These findings indicate that aquaponic systems are capable of creating a culture environment that supports the overall biological performance of fish.

CONCLUSION

Based on the findings of this study on the effects of different aquaponic system designs on the growth and survival of Nile tilapia (*Oreochromis niloticus*), it can be concluded that the aquaponic systems significantly affected both growth performance and survival rate (SR) under the conditions of this experiment. The Deep Water Culture (DWC) treatment produced the highest absolute weight gain, reaching 8.5 g, and achieved a survival rate of 100%. Meanwhile, the greatest absolute length gain was observed in both the NFT and DWC treatments, each reaching 3.6 cm. The highest specific growth rate (SGR) was recorded in the NFT treatment, at 1.63% day^{-1}.

RECOMMENDATION

Further research should be conducted using different fish stocking densities, a wider range of plant species, and longer rearing periods to obtain more comprehensive results. Water quality assessment should also be expanded by including additional chemical parameters, such as ammonia (NH_3), nitrite (NO_2^-), and nitrate (NO_3^-), measured periodically to provide a more detailed understanding of aquaponic system dynamics. In addition, an economic analysis is recommended to evaluate the production cost efficiency of each system, thereby providing a basis for consideration in commercial-scale applications.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Dharmawangsa University for its facilities and academic support, and to the Wet Laboratory of the Faculty of Fisheries for providing the infrastructure and research facilities required for this study. The authors also extend their appreciation to the first supervisor, Dr. Bambang Hendra Siswoyo, S.Pi., M.Si., and the second supervisor, Dwi Tika Afriani, S.Si., M.Pd., for their invaluable guidance and direction. Appreciation is also given to fellow researchers in the Wet Laboratory for their technical assistance and scientific discussions, as well as to the author’s parents for supporting the funding of this research. The assistance and support of all parties were instrumental in the completion of this study and the preparation of this article.

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