Omni-Akuatika, 21 (2): 92 - 107, 2025
ISSN: 1858-3873 print / 2476-9347 online
Research Article
journal homepage: http://ojs.omniakuatika.net

The Effectiveness of Different Plant Types in Reducing Total Ammonia Nitrogen and Increasing Growth of Goldfish (*Carassius auratus*) In Aquaponic Systems

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Received 29 August 2024; Revised 26 February 2026, Accepted 25 March 2026; Available online 5 June 2026, Published 5 June 2026

ABSTRACT

Goldfish is one of Indonesia's most popular ornamental fish due to their high economic value. The high market demand for goldfish led to increased production and intensified cultivation. The intensification can impact water quality and increase waste production. This can affect the availability of supportive cultivation land and increase the water demand. Using an aquaponic system in Goldfish cultivation is a viable solution that can help maintain water quality and reduce high waste production. This study aims to evaluate different types of plants in reducing Total Ammonia Nitrogen (TAN) and assess the impact of different plant types on goldfish growth. This study used goldfish with a stocking density of 12 fish in each container (15 liters). The study employs an experimental method and a completely randomized design (CRD) with 4 treatments and 3 replications. The treatments of Goldfish culture were without plants (A), *Lactuca sativa (*B), *Amaranthus tricolor* (C), and *Brassica oleracea* (D). The observed variables included Dissolved Oxygen, pH, temperature, TAN, nitrate, absolute fish weight, absolute fish length, plant length, Feed Conversion Ratio, Specific Growth Rate, and Survival Rate. The results indicated that different plant types significantly affected TAN reduction and goldfish growth ($P<0.05$). The best TAN reduction and growth were observed with A. tricolor (95% probability). *Amaranthus tricolor* effectively reduced TAN levels and enhanced goldfish growth. This study provides valuable information on the impact of different plant types in lowering TAN levels and improving goldfish growth in an aquaponic system.

Keywords: hydroponics, kale, lettuce, recirculating, spinach

ABSTRAK

Ikan mas koki merupakan salah satu ikan hias yang banyak diminati di Indonesia karena memiliki nilai ekonomis yang tinggi. Tingginya permintaan pasar pada ikan mas koki berdampak pada peningkatan produksi dan intensifikasi budidaya. Adanya intensifikasi budidaya berpengaruh terhadap penurunan kualitas air dan peningkatan hasil limbah budidaya yang tinggi. Hal itu berdampak terhadap ketersediaan lahan budidaya yang mendukung dan kebutuhan air yang tinggi. Penggunaan sistem akuaponik dengan jenis tanaman berbeda merupakan salah satu solusi yang dapat menjaga kualitas air dan mengurangi hasil limbah budidaya yang tinggi. Tujuan dari penelitian ini berguna untuk mengkaji jenis tanaman yang berbeda dalam menurunkan Total Ammonia Nitrogen (TAN); mengkaji pengaruh jenis tanaman yang berbeda terhadap pertumbuhan ikan mas koki. Penelitian ini menggunakan ikan mas koki dengan padat tebar 12 ekor per kolam (15 Liter). dengan menggunakan metode eksperimental dan rancangan acak lengkap (RAL) 4 perlakuan 3 ulangan. Perlakuan tersebut adalah tanpa tanaman (A), *L. sativa* (B), *A. tricolor* (C), dan *B. oleracea* (D). Variabel yang diamati adalah *Dissolved Oxgyen*, pH, Suhu, TAN, Nitrat, bobot mutlak ikan, panjang mutlak ikan, panjang tanaman, *Feed Convertion ratio*, *Specific Growth Rate*, dan *Survival Rate*. Berdasarkan hasil penelitian, bahwa penggunaan jenis tanaman yang berbeda berpengaruh terhadap penurunan TAN dan pertumbuhan ikan mas koki ($P<0,05$). Penurunan TAN dan pertumbuhan terbaik didapatkan pada tanaman *A. tricolor* (probabilitas 95%). *A. tricolor* dapat menurunkan kandungan TAN dan meningkatkan pertumbuhan ikan mas koki.

http://dx.doi.org/10.20884/1.oa.2025.21.2.1186

Penelitian ini berguna dalam memberikan informasi mengenai pengaruh jenis tanaman yang berbeda dalam menurunkan nilai TAN dan meningkatkan pertumbuhan Ikan mas koki pada sistem akuaponik.

Kata kunci: hidroponik, kale, selada, resirkulasi, bayam

1. Introduction

The goldfish (*Carassius auratus*) is a popular freshwater ornamental fish widely favored by the community (Patil *et al*., 2019; Amara *et al*., 2021; Corrêa *et al*., 2023). The popularity of *C. auratus* is due to its diverse colors and unique shapes, which presents promising business potential (Gurung *et al*., 2018; Patil *et al*., 2019). The *C. auratus* has significant business potential for development due to its high economic value and a Large market (Andriani *et al*., 2023; Corrêa *et al*.,2021; Huang *et al*., 2023). Based on data from the Ministry of Maritime Affairs and Fisheries, the national production value of Indonesian goldfish in 2024 reached approximately USD 48,000 (current exchange rate) with a total production of 105,975,767 fish (MoMAF, 2025). This figure represents a significant increase of 36% compared to 2023, which recorded a production value of approximately USD 35,000 with a total production of 86,857,690 fish (MoMAF, 2024). This increase reflects the positive growth of the national goldfish cultivation sector, both in terms of production volume and economic value. The increase in *C. auratus* production can impact the availability of supportive cultivation land and the decline in water quality in cultivation ponds (Wang *et al*., 2022; Corrêa *et al*., 2023). The yearly rise in goldfish production affects the availability of good water sources and supportive cultivation land, which can lead to declining water quality and productivity in goldfish cultivation. The aquaponic system is a viable solution for sustainable cultivation and maintaining water quality (Ibrahim *et al*., 2023). The aquaponics system helps maintain water quality and mitigates the limitations of intensive, non-environmentally friendly cultivation land (Wang *et al*., 2022; Chowdbury *et al*., 2024). This system has been proven to reduce water quality decline and increase production (Wang *et al*., 2022; Hamdani *et al*., 2022).

An aquaponic system integrates aquaculture with hydroponics (Tuapatel *et al*., 2019). This method repurposes fish farming waste, such as metabolic byproducts and leftover feed, as fertilizer or nutrients, enhancing the growth of both fish and plants (Stathopoulo *et al*., 2018; Patil *et al*., 2019). Utilizing an aquaponic system in goldfish farming can boost their productivity and growth while promoting sustainable farming technology (Corrêa *et al*., 2021; Nuwansi *et al*., 2017). Furthermore, implementing this system on a large scale can generate high profits, reduce excessive water costs, and is in line with the principles of sustainable farming (Patil *et al*., 2019; Corrêa *et al*., 2021). In this research, the plants used in the aquaponic system are lettuce (*Lactuca sativa*), red spinach (*Amaranthus tricolor*), and kale (*Brassica oleracea*). These plants act as biofilters, removing toxins (ammonia) from the aquaculture wastewater (Ibrahim *et al*., 2023; Amara *et al*., 2021; Corrêa et al., 2021). Integrating plants in the aquaponic system helps maintain water quality during goldfish cultivation. Lettuce, red spinach, and kale serve as phytoremediators. Plants in aquaponic absorb and eliminate both organic and inorganic compounds from the waste (Cifuentes-Torres *et al*., 2021; Ghicana, 2024). Lettuce (*Lactuca sativa*) is commonly used in aquaponic systems due to its rapid growth and ease of cultivation (Pérez-Urrestarazu *et al*., 2019; Wang *et al*., 2022). Red spinach (*Amaranthus tricolor)* can function as a plant biofilter in the aquaponic system because of its high nutrient absorption rate (Babatunde *et al*., 2019). Additionally, kale (*Brassica oleracea)* is a nutrient-dense plant that quickly absorbs nutrients in the aquaponic system and can be cultivated in a limited space (Dewanti *et al*., 2019; Hairani *et al*., 2022; Kimera *et al*., 2023).

In previous studies, different plant species have been used in goldfish aquaponic systems. For example, Amara *et al*. (2021) and Binawati *et al*. (2023) found that *Lactuca sativa* is an effective biofilter. This is supported by earlier research on goldfish (Sirakov *et al*., 2018; Byrd and Jha, 2022), catfish (Darmawan *et al*., 2020; Wijaya, 2018; Fajeriana *et al*., 2018; Sarmento *et al.,* 2020), and koi (Gumelar *et al*., 2017). There hasn't been much research on using *Amaranthus tricolor* as a filtration plant in goldfish aquaponics. However, studies on another spinach species, *Spinacia oleracea*, by Shete *et al*. (2013), Rajalakshmi *et al*. (2022), and Tsoumalakou *et al*. (2023) indicate that spinach can maintain good water quality in aquaponic systems. *Amaranthus tricolor* benefits from a taproot system that easily absorbs nutrients (Ibrahim *et al*., 2021). Research on using *Brassica oleracea* as a biofilter in goldfish aquaponics is also limited. However, *Brassica oleracea* has been studied in other aquaponic systems with species like tilapia (Kimera *et al*., 2023; Simanullang *et al*., 2023) and catfish (Hairani *et al*., 2022).

This study was conducted in order to evaluate the effects of different plant species in an aquaponic system on Total Ammonia

Nitrogen (TAN), nitrate levels in water, growth, and the survival rate of goldfish.The study aimed to determine which plant species are most effective in reducing TAN and nitrate levels while enhancing growth and survival in aquaponic systems. This research offers valuable insights into how different plants affect aquaponics, helping to identify the best options for maintaining water quality and supporting goldfish growth and survival. Additionally, it can be one of the solutions to have sustainable goldfish farming practices that minimize water use and require limited land.

2. Materials and methods

This research was conducted using an experimental method with a Completely Randomized Design (CRD). The CRD in this study comprised 4 treatments, each with 3 replications per experimental unit. The treatments were based on previous studies (Kadarini *et al*., 2022; Andriani *et al*., 2023) and included: Treatment A (system without plants), Treatment B (aquaponics with lettuce, *Lactuca sativa*), Treatment C (aquaponics with red spinach, *Amaranthus tricolor),* and Treatment D (aquaponics with kale, *Brassica oleracea*). This study occurred about 45 days in total, from December 22, 2023, to February 4, 2024, at the Base Camp of PT Mina Papilon.

2.1 System Design

The design or containers used in the study are 12 plastic container vessels each with a 15-liter capacity. These vessels were initially cleaned using a Potassium Permanganate solution, and then sun-dried for an hour. Once removed from drying, the vessels were left to stand briefly before being filled with water. Subsequently, a system setup was conducted by preparing a water pump for water flow. Following this step, preparations for the plant maintenance media were made by setting up 12 hydroponic tank plant containers with pre-pierced Styrofoam. This was followed by installing 12 PVC pipes and L pipes for each treatment. Finally, water quality monitoring was carried out. The model utilized in this system is the Deep Flow Technique (DFT) which can be seen in (**Figure 1**). The system used is a modified aquaponic technique, employing continuous water flow to supply nutrients. The DFT was a modification method that necessitated significant quantities of water and nutrients (Wibowo, 2021; Fauza *et al*., 2021).

2.2 Research Procedure

The research procedure involved preparations of tools and materials, maintenance containers, test fish, plants, and feed. Plant seeding was carried out using Rockwool as the planting medium by moistening the medium with water, creating holes in the middle, and inserting plant seeds one by one. Once the plants sprouted, they were exposed to sunlight for growth. The plant seeding process lasted for 12-15 days until the plants were ready for transplanting. The aquaponic system used in this study was the DFT. This DFT system is a combination of Nutrient Film Technique (NFT) and Deep Water Culture (DWC) systems. The operation of this system involves installing inlet and outlet pipes with the help of a water pump to ensure continuous water flow as a nutrient supplier for the cultivated plants and fish. The fish species used in this study was *C. auratus* with a size range of 3-5 cm at a stocking density of 12 fish per tank. Fish were selected based on uniform size, absence of defects, and good health condition. Before stocking, acclimatization was conducted.

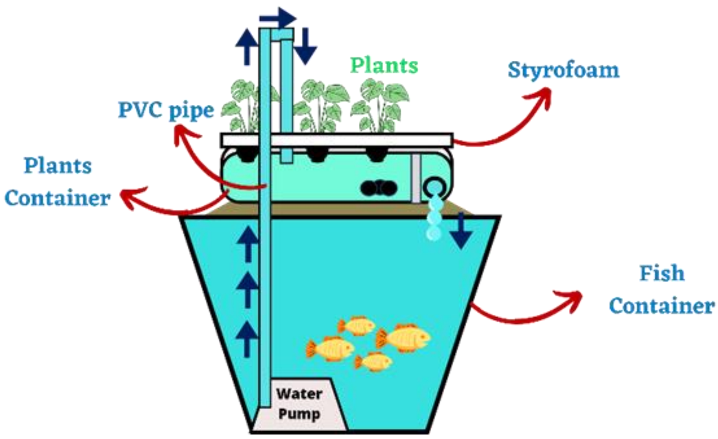

Figure 1. Model of Deep Flow Technique Aquaponic Systems

The maintenance process lasted for 30 days. Fish feed was used with Commercial feed PF 1000 provided twice a day in the morning and evening using the satiation method. Plant maintenance involved ensuring that rockwool was always moistened with water.

2.3 Water Quality Parameter

The parameters measured in the study included temperature, pH, dissolved oxygen (DO) levels, total ammonia nitrogen (TAN), and Nitrate content. The DO and temperature values were obtained using a provided DO meter (JPB-70A). The pH value was determined using a pH meter.

The TAN and nitrate measurement were conducted on laboratory samples with the MN-Macherey test kit to determine the TAN and nitrate content in the aquaponic system. The temperature, pH and DO measurements were taken in the morning and evening every day for one month, while TAN and nitrate measurements were conducted at the beginning (Sampling I), middle (Sampling II), and end of the study (Sampling III).

2.4 Survival and Growth Performance

Absolute weight and length gain, feed conversion rate, and survival were evaluated during the experimental period. Measurement of fish weight and length was carried out every week.

2.5 Absolute weight gain

Absolute weight gain (W) was calculated based on some previous studies:

$$W = Wt - Wo$$

Where:
W is weight gain (g)
Wt is the final average weight (g)
Wo is the initial average weight (g)

(Fazil *et al*., 2017; Kadarini *et al*., 2022; Andriani *et al*., 2023)

2.6 Absolute length gain

Absolute length gain (L) was calculated according to previous studies:

$$L = Lt - Lo$$

Where:
L is length gain (cm)
Lt is the final length (cm)
Lo is the initial length (cm)

(Fazil *et al*., 2017; Kadarini *et al*., 2022; Andriani *et al*., 2023)

2.7 Specific growth rate (SGR)

Specific growth rate (SGR) was determined following to some previous studies:

$$SGR = \frac{\text{Ln Wt} - \text{Ln W0}}{t} \times 100\%$$

Where:
SGR is Specific growth rate (%·day^{-1});
Wt is Weight of fish at the final study (g);
W0 is Weight of fish at the initial study (g);
t is the rearing period (days)

(Shete *et al*., 2013; Kizak and Kapaligoz, 2019; Saputra and Martudi, 2023)

2.8 Feed conversion ratio (FCR)

Feed conversion ratio (FCR) was calculated according to previous studies:

$$FCR = \frac{F}{(Wt + D) - W0}$$

Where:
FCR is Feed conversion ratio
F is the weight of feed eaten (g)
Wt is the final biomass (g)
Wo is the initial biomass (g)
D is the biomass of dead fish (g)

(Kizak and Kapaligoz, 2019; El Rahmini *et al*., 2021; Saputra and Martudi, 2023)

2.9 Survival Rate

Survival rate (SR) was calculated as mentioned in previous studies:

$$SR = \frac{\text{Total live fish at the final study}}{\text{Total fish}} \times 100\%$$

Where:
SR is survival rate (%)
No is the number of fish at the initial study (individual)
Nt is the number at the final study (individual)

(Kizak and Kapaligoz, 2019; Andriani *et al*., 2023; Saputra and Martudi, 2023)

2.10 Plant length growth

Plant length growth (cm) was calculated based on the formula used in previous studies:

$$L = Lt – Lo$$

Where:
L is length gain (cm)
Lt is length at the final study (cm)
Lo is length at the initial study (cm)

(Hapsari *et al*., 2020; Sarmento *et al*., 2020; Byrd and Jha, 2022)

2.11 Analysis Data

Temperature (^oC), pH, and dissolved oxygen (DO) (mg/L) data were analyzed descriptively by comparing the observed values with the optimal standard ranges set by National Standardization Agency (NSA), Indonesia. Meanwhile, normality and homogeneity tests were conducted to verify the assumptions of data distribution and variance for TAN, nitrate, fish body weight gain, body length gain, SGR, FCR, and SR before statistical analysis. If the data is found to be homogeneous and normally distributed, an Analysis of Variance (ANOVA) is employed to determine the treatment effects on the variations between plants and fish. Moreover, Duncan's multiple range test is used to identify significant differences and effects in each treatment. For data that is not normal or homogeneous, the Mann-Whitney test is applied to assess the differences between two distinct data sets. The growth of plant length was analyzed descriptively to see the extent of its development.

3. Results and Discussion

3.1. Results

3.1.1 Water quality

The range and average concentration of DO and temperature values across all treatments during the study remained within the optimal range for carp cultivation, with DO levels >3 mg/L and temperatures ranging from 22 to 26°C, in accordance with NSA 7733 (2018). The average pH value was slightly below the optimal range for carp cultivation in Treatment A (morning and evening) and Treatment B (morning). The ranges and average values of DO, temperature, and pH are provided in **Table 1**.

Overall TAN averages values were within the optimal range for goldfish cultivation. Concentrations exceeding the upper optimal threshold were only observed in treatment A at the beginning of the study. This value was also the highest recorded among all treatments during the study period. Across all three sampling times, treatment A consistently showed the highest TAN values, while treatment D consistently showed the lowest values. The TAN values also appeared to decrease as the study progressed. This occurred in all treatments, except for D, which began to stabilize in the third sampling. Complete TAN data are presented in **Table 2**.

Throughout the study period, nitrate average concentrations in all treatments remained within the optimal range for goldfish cultivation. Similar to the pattern observed for TAN, Treatment A consistently demonstrated the highest nitrate concentrations compared to the other treatments at each sampling time. Conversely, the lowest nitrate values were consistently recorded in Treatment C. In contrast to the decreasing TAN values as the study progressed, nitrate values remained relatively stable across all treatments (**Table 3**).

Table 1. Values of dissolved oxygen (DO), temperature and pH during study

	Time	Treatments				Optimal values*
		A	B	C	D	
DO (mg/L)	08.00	4.1-4.9 (4.36±0.16)	4.4-4.9 (4.54±0.13)	4.5-5.1 (4.67±0.17)	4.5-5.0 (4.55±0.15)	>3
	16.00	4.0-4.9 (4.35±0.16)	4.5-4.9 (4.52±0.13)	4.4-5.2 (4.66±0.14)	4.5-4.9 (4.56±0.15)	
Temperature (℃)	08.00	24.4-27.7 (25.8±0.8)	25.0-27.5 (26.2±0.58)	25.1-27.8 (25.9±0.5)	23.2-26.9 (25.4±0.84)	22 – 26
	16.00	24.2-26.7 (26.3±0.62)	24.1-26.2 (25.6±0.5)	24.9-26.4 (25.8+0.55)	25.0-28.6 (24.8±0.94)	
pH	08.00	5.5-5.9 (5.8±0.39)	5.9-6.8 (5.9±0.32)	5.8-6.5 (6.2±0.24)	5.9-6.5 (6.1±0.22)	6.0-7.8
	16.00	5.5-5.9 (5.9±0.35)	5.8-6.6 (6.0±0.35)	5.9-6.6 (6.2±0.25)	5.8-6.4 (6.0±0.24)	

*NSA 7733 (2018)

Note: Treatment A (system without plants), Treatment B (aquaponics with lettuce, *Lactuca sativa*), Treatment C (aquaponics with red spinach, *Amaranthus tricolor),* and Treatment D (aquaponics with kale, *Brassica oleracea*).

Table 2. Values of Total Ammonia Nitrogen (TAN) during study

Sampling	TAN values (mg/L)				
Time	A	B	C	D	Optimal value*
I (beginning of study)	$1.13 \pm 0.03^{a,1}$	$0.93 \pm 0.03^{b,1}$	$0.79 \pm 0.03^{c,1}$	$0.68 \pm 0.05^{d,1}$	
II (middle of study)	$0.62 \pm 0.02^{a,2}$	$0.42 \pm 0.03^{b,2}$	$0.38 \pm 0.01^{b,2}$	$0.24 \pm 0.03^{c,2}$	<1.0
III (end of study)	$0.50 \pm 0.04^{a,3}$	$0.33 \pm 0.03^{b,3}$	$0.29 \pm 0.01^{b,3}$	$0.23 \pm 0.01^{c,2}$	

* Somerville *et al*. (2014)

Note: Treatment A (system without plants), Treatment B (aquaponics with lettuce, *Lactuca sativa*), Treatment C (aquaponics with red spinach, *Amaranthus tricolor),* and Treatment D (aquaponics with kale, *Brassica oleracea*). Mean±SD value with different superscripts letter between treatment showed significant different (p<0.05); mean±SD value with different superscript numbers between sampling time showed significant different (p<0.05).

Table 3. Values of nitrate during study

Sampling	Nitrate values (mg/L)				
Time	A	B	C	D	Optimal value*
I (beginning of study)	$26.3 \pm 0.55^{a,1}$	$23.8 \pm 0.26^{c,1}$	$22.0 \pm 0.32^{d,1}$	$25.3 \pm 0.30^{b,1}$	
II (middle of study)	$28.9 \pm 0.37^{a,2}$	$25.1 \pm 0.55^{c,1}$	$23.2 \pm 0.25^{d,2}$	$26.6 \pm 0.15^{b,1}$	<50.0
III (end of study)	$27.8 \pm 0.46^{a,2}$	$24.5 \pm 0.55^{c,1}$	$21.7 \pm 0.30^{d,1}$	$25.5 \pm 0.20^{b,1}$	

* Deswati *et al*. (2020)

Note: Treatment A (system without plants), Treatment B (aquaponics with lettuce, *Lactuca sativa*), Treatment C (aquaponics with red spinach, *Amaranthus tricolor),* and Treatment D (aquaponics with kale, *Brassica oleracea*). Mean±SD value with different superscripts letter between treatment showed significantly different (p<0.05); mean±SD value with different superscripts number between sampling time showed significantly different (p<0.05).

This trend indicates that the treatments differed in their capacity to regulate or utilize dissolved nitrogen compounds in the system. Although all measured TAN and nitrate levels were within acceptable limits for goldfish cultivation, the consistently higher concentrations in Treatment A, i.e. system without plants, indicated the lowest assimilation or removal efficiency of TAN and nitrate compared to the other treatments using plants, particularly Treatment D with *B. oleracea* in removing TAN, and Treatment C with *A. tricolor,* in removing nitrate. It is evident that the use of plants significantly impacts the efficiency of TAN and nitrate reduction in the aquaponics system in this study.

3.1.2 Fish Growth Parameter

The weight and length growth of goldfish in treatment A showed the lowest values compared to other treatments using plants. Similarly, the FCR, SGR, and SR values were also observed (**Table 4**). The best weight and length gains were shown in goldfish in treatments B and C. Meanwhile, the best FCR values were in treatments C and D. For the SGR value, the best was in treatment C. The SR value in the treatment using plants showed the same value, namely 100%. Complete data is presented in **Table 4**.

Fish survival and growth performance are highly dependent on good water quality. The better the water quality, the higher the fish survival rate and growth performance. In aquaponics systems, water quality is significantly influenced by the plants' ability to reduce TAN and nitrate concentrations. These results indicate that each plant species exhibits a different capacity to assimilate TAN and nitrate. The *B. oleracea* demonstrated the strongest ability to assimilate TAN compared to other plants, as reflected by consistently lower TAN concentrations than those observed in *L. sativa* and *A. tricolor* treatments, as presented in **Table 2**. On other hand, aquaponics with *A. tricolor* consistently showed the lowest nitrate concentrations among all treatments (**Table 3**), indicating that *A. tricolor* utilizes nitrate more efficiently than other plant species.

3.1.3 Plant Growth Parameter

Plant length measurements revealed growth in all three plant species. Plants in Treatment B grew to nearly three times their initial size. Meanwhile, plants in Treatments C and D grew to approximately twice their initial length. The results of plant measurements are shown in **Table 5**.

Table 4. Goldfish growth parameters during study

Growth parameter	Treatments			
	A	B	C	D
Initial weight (g)	2.27±0.5	2.29±0.12	2.24±0.11	2.35±0.13
Final weight (g)	3.21±0.28	4.08±0.03	4.53±0.02	4.09±0.03
Growth body weight (g)	0.94±0.08^{a}	1.79±0.03^{b}	2.28±0.05^{d}	1.73 ±0.07^{c}
Initial length (cm)	2.26±0.12	2.56±0.14	2.63±0.22	2.56±0.22
Final length (cm)	3.23±0.29	4.8±0.41	5.1±0.44	4.53±0.31
Growth body Length (cm)	1.02±0.17^{a}	2.23±0.05^{bc}	2.46±0.23^{c}	1.96±0.15^{b}
FCR	2.08±0.04^{c}	1.75±0.05^{b}	1.41±0.09^{a}	1.64±0.04^{ab}
SGR (%/day)	1.15±0.03^{a}	1.83±0.02^{b}	2.35±0.06^{d}	1.92±0.08^{c}
SR (%)	94.44±0.34^{a}	100.00±0.00^{b}	100.00±0.00^{b}	100.00±0.00^{b}

Note: Treatment A (system without plants), Treatment B (aquaponics with lettuce, *Lactuca sativa*), Treatment C (aquaponics with red spinach, *Amaranthus tricolor),* and Treatment D (aquaponics with kale, *Brassica oleracea*). Mean±SD value with different superscripts letter between treatment showed significantly different (p<0.05)

Table 5. Plant growth parameters during study.

Growth Parameter	Treatments			
	A	B	C	D
Initial Length average (cm)	-	4.5±0.1	5.6±0.17	4.03±0.25
Final Length average (cm)	-	12.23±0.25	11.46±0.45	8.7±0.26
Growth Length Plant (cm)	-	7.73±0.30	5.86±0.47	4.67±0.35

Note: Treatment A (system without plants), Treatment B (aquaponics with lettuce, *Lactuca sativa*), Treatment C (aquaponics with red spinach, *Amaranthus tricolor),* and Treatment D (aquaponics with kale, *Brassica oleracea*).

3.2. Discussion

3.2.1 Water quality parameters

Water quality is crucial for the success of fish farming in aquaculture (Yavuzcan Yildiz *et al*., 2017; Hapsari *et al*., 2020; Nishanth *et al*., 2024; Chowdhury *et al*., 2024). According to (**Table 1**), the water quality parameters seem to be optimal for goldfish to grow. One of the water quality parameters that can affect the growth of fish is DO (Hairani *et al*., 2022; Ibrahim *et al*., 2023). Dissolved oxygen is one key parameter that affects both fish health and plant growth (Andriani *et al*., 2023). The study found DO levels ranging from 4.0 to 5.2 mg/L. The highest DO level was recorded in *A. tricolor* (C) treatment at 4.67±0.17 mg/L (**Table 1)**, while the lowest was in the treatment without plants (A), at 4.35±0.16 mg/L (**Table 1**). The high DO level is likely due to optimal water temperature and effective nutrient absorption by *A. tricolor* (C). Effective absorption by these plants enhanced oxygen levels in the aquaponic system. Additionally, dissolved oxygen levels are influenced by ammonia levels in the water. High ammonia can lower dissolved oxygen concentrations (Hasibuan *et al*., 2021). The DO levels of 4.0 to 5.2 mg/L are within the optimal range. According to NSA 7733 (2018) and Sinaga *et al*. (2024), the DO range above 3 mg/L is ideal for goldfish farming. This finding is consistent with earlier studies by Andriani *et al*. (2023) and Saputra *et al*. (2023), which suggest that a minimum DO level of 4 mg/L is beneficial for goldfish growth. Furthermore, insufficient oxygen can negatively impact goldfish growth.

Temperature significantly impacts the growth and survival of goldfish (Setijaningsih *et al*., 2022). In this study, temperatures ranged from 23.8-26.7℃, with the highest average recorded in the plant-free treatment (A) at 26.3±0.62℃ (**Table 1**), and the lowest in the *B. oleracea* (D) treatment at 24.8±0.94℃ (**Table 1**). These temperature variations are likely due to weather conditions and elevated TAN (Total

Ammonia Nitrogen) levels in the ponds (Fabula *et al*., 2023). High TAN levels can increase water temperature and pH (Hasibuan *et al*., 2021; Gichana, 2024). Weather, especially rain, also affects pond temperatures in aquaponic systems (Pierrenia *et al*., 2021; Vasdravanidis *et al*., 2022). Low temperatures can reduce the appetite and growth of goldfish (Andriani *et al*., 2023; Pierrenia *et al*., 2021; Corrêa *et al*., 2023). The temperature range of 23.8-26.7℃ in this study is acceptable. According to NSA 7733 (2018), the optimal temperature range for goldfish farming is 22-26℃. Wang *et al*. (2023) also indicated that 22-25℃ is ideal for goldfish maintenance. This range supports the growth of both fish and aquaponic plants. In addition, Khieokhajonkhet *et al.* (2023) reported that goldfish reared at temperatures above 30 °C showed a significant decrease in pigmentation and total carotenoid concentration in muscle, skin, and serum at the tenth week of rearing. High temperatures can decrease dissolved oxygen and increase ammonia levels (Hasibuan *et al*., 2021). Temperature also affects oxygen levels and the activity of nitrifying bacteria (Andriani *et al*., 2023).

The pH level of water is a crucial factor that influences fish stress and survival (Setijaningsih *et al*., 2022; Wang *et al*., 2023). Research indicates that the pH levels in this study ranged from 5.5 to 6.8, with the optimal pH of 6.2±0.24 observed in the *A. tricolor* (C) treatment (**Table 1**). This optimal pH is likely due to the efficient nutrient absorption by *A. tricolor* (C) roots. The lowest pH level of 5.8±0.39 was found in the treatment without plants (A) (**Table 1**), possibly due to declining water quality from leftover feed, fish waste, algae respiration, and increased CO_2 levels (Andriani *et al*., 2023). A pH range of 5.5-6.8 is suitable for goldfish (**Table 1**), it is supported by NSA 7733 (2018), which recommends a pH range of 5-7 for goldfish farming. This also found that a pH range of 6-8.5 supports goldfish growth and survival (Yildiz *et al*., 2017; Kizak and Kapaligoz, 2019). Extreme pH levels can negatively impact fish growth and survival (Hasibuan *et al*., 2021; Andriani *et al.*, 2023). Nitrifying bacteria activity is also influenced by pH levels. According to study Andriani *et al*. (2023) and Corrêa *et al*. (2023), extreme pH levels can impact to bacterial activity and affecting water quality in aquaponics systems.

Total Ammonia Nitrogen (TAN) is a nitrogen compound that impacts the survival and growth of goldfish (Nuwansi *et al*., 2017; Kizak and Kapaligoz, 2019). This study found TAN levels ranging from 0.23±0.01 to 1.13±0.03 mg/L (**Table 2**), with the best TAN level in the aquaponic system recorded in the *B. oleracea* (D) treatment at 0.23±0.01 mg/L. This is due to the effective TAN absorption by the deep and widespread root system of *B. oleracea* (D), which helps absorb ammonia and nutrients necessary for plant growth (Babatunde *et al*., 2019; Simanullang *et al*., 2023). Although *B. oleracea* (D) absorbs TAN more efficiently than *L. sativa* (B) and *A. tricolor* (C), the latter two also absorb TAN well within the optimal range. ANOVA analysis ($P<0.05$) indicates that different plant types significantly affect TAN reduction, due to effective absorption by plant roots. The TAN levels in this study are within the optimal range, as the optimal TAN limit is less than 1 mg/L (Somerville *et al*., 2014; Byrd and Jha, 2022). Previous studies, such as Babatunde *et al*. (2019), reported similar TAN levels in aquaponic systems, ranging from 0.13±0.01 to 1.05±0.03 mg/L. Patil *et al*. (2019) also found TAN levels of 0.11±0.01 to 0.15±0.20 mg/L, suitable for goldfish farming. High TAN levels can affect water quality parameters like temperature and pH, with higher TAN correlating with higher pH and temperature (Hasibuan *et al*., 2018). Andriani *et al*. (2023) and Corrêa *et al*. (2023) also found that high TAN levels negatively impact pond water quality, fish growth, and survival.

The highest TAN level was observed in the treatment without plants (A) at 1.13±0.03 mg/L (**Table 2**), due to poor water quality and insufficient nitrifying bacteria activity (Hasibuan *et al*., 2021; Nishanth *et al*., 2024). High TAN levels are influenced by suboptimal water quality, such as pH (Fabula *et al*., 2023). In the *L. sativa* (B) and *A. tricolor* (C) treatments, the TAN levels decreased to 0.93±0.03 mg/L and 0.79±0.03 mg/L, respectively, due to effective absorption by plant roots. *L. sativa* and *A. tricolor* thrive in aquaponic systems because their root systems efficiently absorb nutrients (Gichana *et al*., 2019; Simanullang *et al*., 2023). Poorly degraded ammonia is toxic to fish. Ammonia levels in aquaponic systems fluctuate due to factors like fish density, feed type, and environmental conditions (Wahyuningsih *et al*., 2015; Yildiz *et al*., 2017; Deswati *et al*., 2020). In general, TAN values decreased over the study period in all treatments (Table 2). A decrease in TAN also occurred in Treatment A, even without plants. This indicates that nitrification occurred in Treatment A, possibly due to the growth of nitrifying bacteria. Nitrifying bacteria can thrive in a system if there is organic matter, which will degrade into inorganic matter, and sufficient DO (Harwanto, 2011a).

Nitrate is an oxidation product of ammonia and is essential for plant growth. According to research (**Table 3**), the *A. tricolor* treatment (C) showed the lowest nitrate levels in each sampling, due to the plant's efficient nitrate absorption. *A. tricolor's* deep, adaptive root system facilitates effective nitrate absorption (Nawawi and Saptorini, 2021; Ibrahim *et al*., 2021). While *A. tricolor* had the best results, *L. sativa* (B) and *B. oleracea* (D) also absorbed nitrate well for plant growth. The ANOVA analysis showed that different plant types significantly affected nitrate levels in aquaponic systems (P<0.05), due to effective absorption by plant roots. As the study progressed, nitrate values remained relatively stable across all treatments (**Table 3**).

The nitrate levels in this study, ranging from 26.3±1.05 mg/L to 22.0±0.32 mg/L, are suitable for goldfish survival. Mado *et al*. (2023) indicated that nitrate levels around 10 mg/L are ideal for fish growth, while levels above 50 mg/L can be lethal (Somerville *et al*., 2014; Darwis *et al*., 2019; Deswati *et al*., 2020). Moreover, Fabula *et al*. (2023) and Vandam *et al*., (2017) also found that nitrate levels of 0-40 mg/L are suitable for fish growth. High nitrate levels do not harm fish, as nitrate is not toxic to aquatic organisms (Khater *et al*., 2023; Simanullang *et al*., 2023).

The highest nitrate level in this study was recorded in the treatment without plants (A) at 27.5±0.49 mg/L (**Table 3**), likely due to slow absorption by nitrifying bacteria and lack of direct filtration by plants (Corrêa *et al*., 2023). High nitrate levels may also result from no water changes during maintenance (Dauhan *et al*., 2014). Nitrate is a form of nitrogen that's directly utilized by plants through root phytoremediation (Setijaningsih *et al*., 2022). Aquaponic systems, which do not require water changes, rely on bacteria to oxidize ammonia in the nitrification process (Dauhan *et al*., 2014; Simanullang *et al*., 2023; Hairani *et al*., 2022). Despite high nitrate levels, goldfish fry tolerated it well, as indicated by high survival rates. High nitrate levels benefit plant growth, as plant roots support bacteria that help in nitrification, converting ammonia to nitrate (Andriani *et al*., 2023). Plants contribute oxygen (O_2), improving water quality for fish and bacteria. This continuous process sustains the system (Hamdani *et al*., 2022; Setijaningsih *et al*., 2022). The role of the plants in each treatment in isolating TAN and nitrate was demonstrated from the first sampling. This indicates that plants that had been sown for up to two weeks could grow well after being transferred into the system.

3.2.2 Fish Growth Parameters

The best growth rate for goldfish weight was achieved in the *A. tricolor* (C) treatment, with a value of 2.28±0.05 g (**Table 4**). This is likely due to *A. tricolor's* ability to effectively reduce TAN values during nitrification, thereby maintaining water quality and supporting goldfish growth (Ibrahim *et al*., 2021; Wang *et al*., 2023). Factors influencing goldfish growth include food availability, competition for food, and the fish's ability to absorb nutrients (Simanullang *et al*., 2023). Additionally, growth is affected by water quality parameters such as Dissolved Oxygen (DO) and Total Ammonia Nitrogen (TAN) levels (Hairani *et al*., 2022). Low or decreasing DO levels can adversely affect goldfish growth (Hairani *et al*., 2022; Andriani *et al*., 2023). High TAN levels (>1 mg/L) can also stunt goldfish growth (Somerville *et al*., 2014; Byrd and Jha, 2022). ANOVA analysis showed that different plant types significantly affect goldfish weight growth (P<0.05) in aquaponic systems. Fish grow optimally in good water quality conditions. The highest absolute weight was observed in the *A. tricolor* (C) treatment (2.28±0.05 g), while the lowest was in the no-plant treatment (A) (0.94±0.03 g). These results are higher than those in a previous study by Andriani *et al*. (2023), which reported goldfish growth between 0.57±0.07 and 1.70±0.02 g. Efficient food absorption and supportive water quality contribute to fish growth. Moreover, studies by Nishanth *et al*. (2024) and Setijaningsih *et al*., (2022) mention that good water quality like DO, temperature, pH, TAN, and nitrate levels, can significantly impact goldfish growth. According to research by Azhari *et al*. (2018) and Andriani *et al*. (2023), water quality and adequate feeding contribute significantly to fish growth.

The lowest growth rate of goldfish weight was observed in the treatment without plant (A), with a value of 0.94±0.03 g (**Table 4**). This is attributed to suboptimal water quality in the aquaponic system. The pH in the no-plant treatment (A) ranged between 5.5 and 6.4, which is too low for optimal goldfish growth, leading to slow growth, disease susceptibility, and reduced productivity (Francis-Flyod *et al*., 2022; Andriani *et al*., 2023). Soleha *et al*. (2022) found that a pH range of 6-9 is ideal for goldfish maintenance. Growth variations are influenced by environmental factors, such as water quality (Patil *et al*., 2019; Pierrenia *et al*., 2021). Adequate feeding ensures that the consumed energy is used for body maintenance and growth (Kizak and Kapaligoz, 2019).

The best goldfish length growth was also in the *A. tricolor* (C) treatment, at 2.46±0.23 cm, due to good feeding and optimal water quality. Environmental changes, such as water quality and feeding, affect goldfish length growth. Efficient feed absorption improves and accelerates growth (Young *et al*., 2023). The ANOVA analysis indicated that different plant types significantly affected goldfish length growth ($P<0.05$) in aquaponic systems. The highest and lowest lengths were in the *A. tricolor* (C) (2.46±0.23 cm) and no-plant (A) (0.96±0.15 cm) treatments, respectively. These results are lower than those of Andriani *et al*. (2023), who reported lengths between 2.36±0.05 and 3.33±0.24 cm. Feeding and environmental conditions significantly impact goldfish length growth, and water quality, particularly ammonia levels, affects growth rates (Simanullang *et al*., 2023). High ammonia content can slow down fish growth (Hasibuan et al., 2021; Corrêa *et al*., 2023). According to this study, the lowest length growth was in the no-plant treatment (A), at 0.96±0.15 g, due to inadequate food absorption and suboptimal water quality. The pH in the no-plant treatment (A) was between 5.5 and 6.4, affecting growth rates by making fish more susceptible to disease and less productive (Andriani *et al*., 2023).

Feed Conversion Ratio (FCR) is how efficiently fish absorb and utilize their food. According to this study (**Table 4**), the *A. tricolor* treatment achieved the best FCR at 1.16±0.09 (**Table 4**), reflecting efficient food utilization supported by good food availability (Darmawan *et al*., 2020; Amara *et al*., 2021). Proper nutrition and good water quality are essential for goldfish to grow. ANOVA analysis revealed that different plant types significantly affect FCR ($P<0.05$) in aquaponic systems. The FCR values ranged from 1.16±0.09 to 1.78±0.06, were better than the research by Kizak and Kapaligoz (2019), who reported FCR values of 2.01-2.04 over 60 days. Efficient food absorption and supportive water quality likely contributed to these results (Gichana *et al*., 2019). Lower FCR values indicate better feed utilization efficiency (Sitompul *et al*., 2021; Gichana *et al*., 2019). Poor water quality can reduce fish appetite (Rahimi *et al*., 2021). A previous study by Amara *et al*. (2021) also suggested that suboptimal water quality impacts FCR and growth. Dissolved oxygen (DO) is critical, as low oxygen levels can stress fish and reduce appetite (Andriani *et al*., 2023). According to this study, the highest FCR was recorded in the no-plant treatment (A) at 1.78±0.06 (**Table 4**), due to inefficient food absorption. High levels of ammonia or Total Ammonia Nitrogen (TAN) can affect fish metabolism and reduce food intake efficiency (Hidayah *et al*., 2021; Simanullang *et al*., 2023).

The Specific Growth Rate (SGR) measures daily growth during the maintenance period. The best SGR in this study was observed in the *A. tricolor* treatment (C) at 2.34±0.06% per day (**Table 4**), attributed to *A. tricolor's* effective ammonia oxidation and nutrient absorption. Efficient nitrification by *A. tricolor* reduces TAN levels, positively affecting goldfish growth (Kizak and Kapaligoz, 2019). Good feeding practices and water quality are crucial for optimal growth (Andriani *et al*., 2023). ANOVA analysis showed significant differences in SGR among plant types in aquaponic systems ($P<0.05$). Duncan's test confirmed significant differences in SGR across treatments. SGR values ranged from 1.15±0.08 to 2.34±0.06% per day, higher than those reported by Prahesti *et al*. (2019), which ranged from 0.93 to 1.59% per day over 35 days. Nuwansi *et al.* (2017) reported similar SGR values of 1.91-1.98% per day. Optimal water quality and proper feeding support high SGR values. *A. tricolor's* deep and adaptive root system allows efficient nutrient absorption in aquaponic systems (Ibrahim, 2021). Adequate dissolved oxygen supports root respiration and nutrient uptake, promoting growth (f *et al*., 2021). The lowest SGR was in the no-plant treatment (A) at 1.15±0.08% per day, due to insufficient nitrification and nutrient availability. The absence of phytoremediation plants slows ammonia oxidation, reducing nutrient availability for goldfish growth (Hidayah *et al*., 2021; Nishanth *et al*., 2024; Simanullang *et al*., 2023). Water quality parameters such as DO, temperature, and pH also affect SGR (Hairani *et al*., 2022; Simanullang *et al*., 2023).

The Survival Rate is a measure used to determine the number of goldfish that remain alive in an aquaponic system. The results obtained from this study were quite satisfactory. The survival rate for goldfish was 100% for the treatments with *L. sativa* (B), *A. tricolor* (C), and *B. oleracea* (D), and 94.44% for the treatment without plants (A). This suggests that the water quality in the aquaponic system was suitable for goldfish growth. This finding is supported by Pierrenia *et al*. (2021), who stated that one of the factors affecting the survival rate percentage is a supportive and suitable environment, such as optimal water quality performance for maintaining fish survival. Based on the data analysis results, the data were found to be non-normal and non-homogeneous, making further testing to determine significant differences in the survival rate percentage impossible. However, another test, the Mann-Whitney test, was conducted. The Mann-Whitney test is useful for determining differences between two independent samples from the same population. The Mann-Whitney test results showed a significant difference between the treatment without plants and the treatments with plants in the aquaponic system. This was indicated by an Asymp. Sig. (2-tailed) value of 0.0001, which is less than 0.05. If the p-value is less than the critical threshold of 0.05, there is a significant difference between the treatment without plants and the treatment with plants.

The survival rate percentages for each treatment in the aquaponic system were still within a good range for goldfish cultivation. This is supported by Andriani *et al*. (2023) and NSA 8110 (2015), which state that a good survival rate for goldfish cultivation ranges from 80-100%. It is suggested that the survival rate is influenced by the environment, including the physical and chemical properties of the water, movement space, and food availability in terms of quality and quantity (Pierrenia *et al*., 2021). Additionally, the environment is a factor that can affect the survival and growth of cultured fish during the maintenance period. Fish experiencing excessive environmental changes, such as an excess of Total Ammonia Nitrogen (TAN), can have their growth and survival impacted during the maintenance period. One factor that ensures the survival of goldfish is the TAN content. Total Ammonia Nitrogen levels exceeding the optimal range during the maintenance period can affect fish growth and survival (Hasibuan *et al*., 2021; Ibrahim *et al*., 2023). The TAN can become toxic to fish because undecomposed compounds negatively impact fish health (Setijaningsih *et al*., 2022; Djaelani *et al*., 2023). Therefore, water quality parameters such as ammonia and other water quality indicators need to be monitored to achieve good growth and survival outcomes (Kadarini *et al*., 2022).

3.2.3 Plants Growth Parameter

The *L. sativa* (B), *A. tricolor* (C), and *B. oleracea* (D) showed increased biomass at the end of the study. The growth of *L. sativa* was 6.26±0.30 cm, *A. tricolor* was 5.86±0.40 cm, and *B. oleracea* was 4.66±0.20 cm (**Table 5**). Water quality significantly affects plants during the nitrification process. Optimal water quality parameters, such as pH and temperature, can aid nitrification and ammonia processing in plants (Hairani *et al*., 2022; Hasibuan *et al*., 2018). Although each plant showed growth, the growth rate was slow. This is probably due to the temperature range during the study is optimal for the fish but not ideal for plant growth. The optimal temperature ranges for *L. sativa* (B), *A. tricolor* (C), and *B. oleracea* (D) differ. The ideal temperature for *L. sativa* (B) is 18-25°C (Simanullang *et al*., 2023), for *A. tricolor*, it is 23-30°C (Krastanova *et al*., 2022), and for *B. oleracea,* it is 25-30°C (Simanullang *et al*., 2023). This variation contributes to the slower growth of *A. tricolor, B. oleracea* and *L. sativa*. Suboptimal temperatures for *plants* can hinder the nitrifying bacteria process, essential for nitrogen oxidation beneficial to plant growth (Zidni *et al*., 2019; Simanullang *et al*., 2023). Another factor influencing plant growth in the aquaponic system is adequate sunlight and a conducive environment. Sunlight is essential for promoting rapid plant growth (Hapsari *et al*., 2020; Ibrahim *et al*., 2023). It serves as an energy source for plant development. Lack of sunlight can hinder growth and development, causing plants to be slow and small due to nitrogen deficiency (Darmawan *et al*., 2020). Additionally, low temperatures, often due to poor weather like rain, can affect plant growth in an aquaponic system by reducing sunlight availability. Insufficient sunlight can slow plant growth (stunted plants) in aquaponic systems and impact to the growth of the fish being raised. Optimal water temperatures allow fish to grow and develop maximally (Nishanth *et al*., 2024).

4. Conclusion

This research concluded that aquaponics with different types of plants significantly affect the reduction of TAN and nitrate concentrations in the water, as well as the growth of goldfish, but it does not significantly impact the survival rate of goldfish in the aquaponic system. Additionally, the best plant for reducing TAN levels, promoting growth, and ensuring the survival of goldfish in the aquaponic system is *A. tricolor* (C). This plant achieved TAN levels of 0.38±0.01 mg/L, weight growth of 2.28±0.05 g, length growth of 2.46±0.23 cm, FCR of 1.16±0.09, SGR of 2.34±0.06%/day, and survival rate of 100%. The use of *B. oleracea* (D) is more effective in reducing TAN levels compared to other plants, while *A. tricolor* (C) is more effective in reducing nitrate levels in the aquaponic system. Therefore, this study is expected to provide fundamental information for more advanced and innovative research in aquaculture and the environmental impact of fish farming.

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