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Evaluation of Efficiency of *Echinodorus palaefolius* (J.F. Macbr.) Involved in the *Clarias gariepinus* (Burchell, 1822) Culture for Water Quality Recovery and Fish Growth Support

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ABSTRACT

Intensive catfish [*Clarias gariepinus*(Burchell, 1822)] cultivation produces organic waste that decreases water quality. The aquaponics system utilizes fish waste for plant growth to produce useful and economical products. This study aims to analyze and evaluate the best density of Mexican sword plant/water Jasmine [*Echinodorus palaefolius* (J. F. Macbr.)] in reducing waste from intensive catfish aquaculture. The research method used a completely randomized design (CRD) with four treatments with three replications. A plastic tub with a size of 38 cm × 12 cm × 30 cm filled with sand was used for plant media, while for catfish rearing containers, a 70 L tub with a water volume of 40 L was used. The fish used in this experiment were catfish fry with a size of 7 cm ± 0.8 cm, a weight of 5.14 g ± 0.45 g, with a stocking density of one fry per liter. Catfish fry were fed with floating pellet feed of 30 % protein content, and the feeding was done at satiation. The treatments were T1 = without plants, T2 = 150 g m^{-2} plants, T3 = 250 g m^{-2} plants, and T4 = 350 g m^{-2} plants. Furthermore, all data were analyzed through ANOVA (One-way analysis of variance) and the Duncan's multiple range test to measure significant variations among the treatments using SPSS (version 17, USA). The results revealed that T4 was the best treatment in terms of nutrient removal efficiency of TAN, NO_2, NO_3, and PO_4 at the rate of 23.80 %, 48.19 %, 52.99 % and 26.11 %, respectively. Moreover, growth performances of fish fry fed diet in T4 also were significantly ($P < 0.05$) higher than other fishes of different treatments. Regarding these findings, *E. palaefolius* could work well to maintain water quality during *C. gariepinus* cultivation and even accelerated *C. gariepinus* growth at the end of the period.

Keywords: Aquaponics technology, Catfish, Economically valuable, Intensive culture, Mexican sword plant, Phytoremediation, Utilization waste, Water Jasmine

1. Introduction

Catfish [*Clarias gariepinus* (Burchell, 1822)] is a very popular commodity for cultivation in Africa, Indonesia, and several other countries in the world because of its fast growth, disease resistance, and wide geographical spread (Elesho *et al.*, 2021). Consequently, catfish production in Indonesia has increased rapidly, accounting for 55 691 t in 2004 and climbed dramatically in 2014, reached 543 774 t (Zahidah *et al.*, 2018). In addition, catfish production from 2017 to 2018 increased from 841.75 × 10^3 t to 1.81 × 10^6 t (114.82 %) (FAO, 2018).

In intensive fish cultivation, only about 80 % of the feed given is consumed, while the remaining 20 % will be wasted (not eaten), and of the 80 % consumed, only about 25 % will be retained. In comparison, the remaining 10% will be wasted through faeces, and 65 % will be excreted as urine (Bureau and Hua, 2010). According to El-Shafai *et al.* (2007), in the intensive cultivation system of tilapia, the nutrients released are around 62 % to 73 % of the total nitrogen and 55 % to 70 % of the total phosphorus divided into particles dissolved. Furthermore, N and P waste can affect water quality parameters such as a decrease in the concentration of dissolved oxygen content and an increase in the concentration of carbon dioxide, ammonia, nitrite, and nitrate (Hlordzi *et al.*, 2020). According to Keramat (2011), the resulting waste could increase dissolved and suspended organic matter in the feed residue, faeces and urine, negatively affecting fish growth even at specific toxic doses. Therefore, the deterioration of water quality leads to retard fish growth (Makori *et al.*, 2017). In a review by Yavuzcan *et al.* (2017), water quality deterioration has a detrimental effect on fish physiology, growth rate, and feed efficiency, resulting in various diseases and even death. Based on those obstacles, it is necessary to find a solution to maintain water quality suitable for *C. gariepinus*, such as applying an aquaponics system.

Aquaponics is the process of maintaining aquatic organisms and plants in symbiosis into one system or several sub-systems (Goddek *et al.*, 2019; Monsees *et al.*, 2017; Pedersen *et al.*, 2012), whereas treated water is circulated freely between aquaculture and hydroponic units in a single loop system (Goddek *et al.*, 2019). The

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principle of the aquaponics system is to utilize fish cultivation waste for plant growth and produce useful and economically valuable by-products (Somerville *et al.*, 2014). The advantages of aquaponics technology compared to conventional fish cultivation technologies are to control water quality, high fish growth and production, and additional income from plants. Plants in aquaponics technology absorb nutrients from waste of fish culture system for their development (Goddek *et al.*, 2019).

The types of plants used in the aquaponics system can be vegetable plants, fruit plants, aquatic plants (aquascape), flower plants or other aquatic plants. Ghaly *et al.* (2005) reported that five types of plants, including *Medicago sativa* L., *Trifolium repens* L., *Avena sativa* L., *Secale cereale* L. and *Hordeum vulgare* L. were able to reduce total solids, COD, NO_3-N, NO_2-N, phosphate and potassium ranging from 54.7 % to 91.0 %, 56.0 % to 91.5 %, 82.9 % to 98.1 %, 95.9 % to 99.5 %, 54.5 % to 93.6 % and 99.6 % to 99.8 %. Handajani *et al.* (2018) also postulated that *Echinodorus palaefolius* (J. F. Macbr) could utilize N and P in *Anguilla bicolor* culture. Water remediation with *E. amazonicus* and *E. palaefolius* significantly reduced TAN, NO_2, NO_3, and PO_4 concentrations in effluent of fish culture system. Unfortunately, no one has used *E. palaefolius* as a phytoremediator agent in the aquaponic system of catfish culture. Thus, that system is expected to improve the performance of fish production.

The purpose of this study was to evaluate the capacity of water Jasmine/Mexican Sword [*Echinodorus palaefolius* (J. F. Macbr.)] plants as phytoremediation agents in aquaponics systems in reducing waste of catfish culture system.

2. Materials and Methods

2.1. Preparation of containers, fish, and plants

Two types of containers were used in this experiment for catfish fry and *E. palaefolius* cultivation. Twelve catfish fries were reared in containers filled with 40 L of water, while *E. palaefolius* was maintained in a tub with volume of 38 cm × 12 cm × 30 cm in length, completed with sand as a planting medium at the bottom of the tub. Meanwhile, this experiment used catfish fries (5.14 g ± 0.45 g) obtained from a group of fish farmers in Malang Regency, with a stocking density of one fish per liter. The placement of fish in the experimental unit was carried out randomly. Before the treatment, catfish was conditioned for 5 d, fed diet of 30 % of protein with a feeding rate of 3 % of the biomass. The frequency of feeding was conducted in the morning (06.00), afternoon (12.00) and evening (18.00) for 30 d. During the conditioning period, the health and vitality of catfish were controlled so that they were still suitable as a sample. Moreover, the aquatic plants obtained from ornamental aquatic plant cultivators were adapted in a fibre bath for 5 d before use.

2.2. Experimental design and data analysis

This study used a completely randomized design with four treatments with three replications. These treatments differed among teach other in the stocking density of *E. palaefolius*: 0 g m^{-2} (T1), 150 g m^{-2} (T2), 250 g m^{-2} (T3) and 350 g m^{-2} (T4). Each treatment was repeated three times.ANOVA and F test used the SPSS version 21 with 95 % confidence level, then further tested using the Duncan's multiple range test to determine whether significant variation among treatment means the treatment effect on each tested variable (Adinurani, 2016).

2.3. Measurements

Water quality measurements were carried out for 30 d (day) after introducing water plants. Water quality parameters were measured every day including temperature, pH, dissolved oxygen (DO), while total amoniacal nitrogen (TAN), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2), phosphate phosphorus (PO_4-P), total suspended solids (TSS), once a week (1 wk=7 d) following Enduta *et al.*, 2011. Measurement of TAN, nitrite, nitrate, and orthophosphate was carried out using a spectrophotometer referring to Rice *et al.* (2017). The following measures were taken: survival rate (SR), total feed consumption, specific growth rate (SGR), absolute length (Al), and feed conversion ratio (FCR) to determine the growth performance of catfish (Liu *et al.*, 2016; Nhan *et al.*, 2019) using Equation (1) to Equation (4):

$$\text{SGR } (\%\ d^{-1}) = \frac{W0 - Wt}{t} \qquad (1)$$

$$\text{Al (cm)} = Lt - L0 \qquad (2)$$

$$\text{FCR} = \frac{F}{Wt - W0} \qquad (3)$$

Note:SGR = Specific growth rate (% d^{-1}); FCR = Feed conversion ratio; Al= Absolute lenght (cm); F= Feed consumption during cultivation (kg);W0 = Initial weight (g); Wt = Final weight (g); W0 = Initial lenght (cm)

Wt = Final lenght (cm);t = Time (day)

$$\text{SR } (\%) = \frac{Nt}{No} \times 100 \qquad (4)$$

Note:SR = Survival rate (%);No= Initial number of fish; Nt = Final number of fish

The calculation of nutrient removal was carried out every 7 d, such as TAN, NO_3, NO_2 and PO_4 (Enduta *et al.*, 2011). The water plant parameters, including wet biomass, were measured at the beginning and end of the experiment. At the beginning and end of the investigation, the total N and PO_4-P in plant tissue were analyzed (Amalia *et al.*, 2014).

2.4. Nutrient removal efficiency

During the experiment, there was a loss of nutrients in the water. The amount of nutrient reduction could be calculated by the following Equation (5) (Zhou *et al.*, 2006).

$$NR = \frac{(Ca - Cb)}{Ca}\ x\ 100 \qquad (5)$$

Note:NR = nutrient removal (%); Ca= nutrient concentration of influent (mg L^{-1}); Cb = nutrient concentration of effluent (mg L^{-1})

3. Result and discussion

3.1. Result

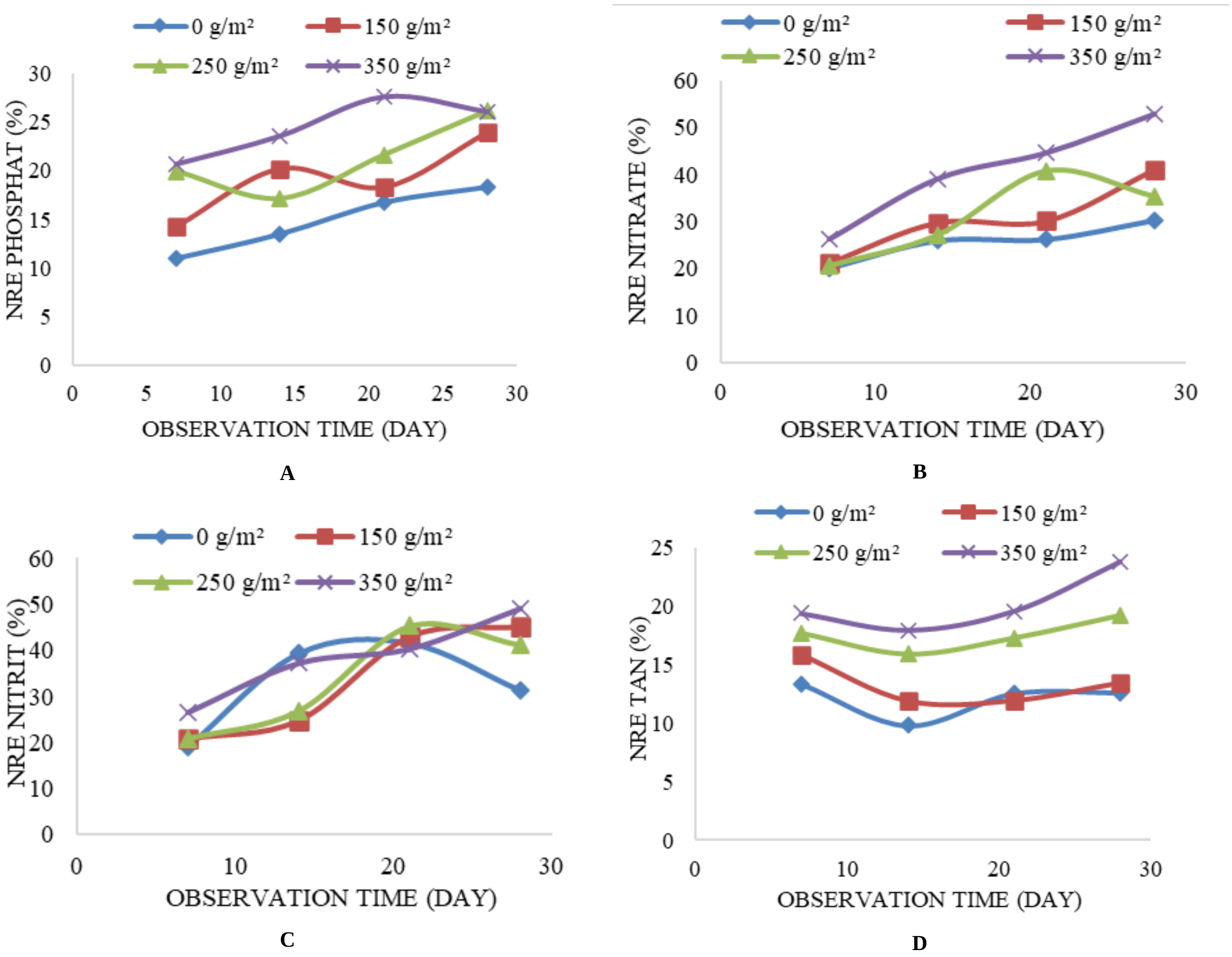
3.1.1. Water quality and nutrient removal efficiency

Measurement of water quality parameters, including temperature, pH, dissolved oxygen (DO), total suspended solids (TSS), total ammonia nitrogen (TAN), ammonia (NH_3), ammonium (NH_4), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), orthophosphate (PO_4-P) were examined for 30 d of catfish rearing (Table 1).

Tabel 1. Water quality in catfish media during 30 d observation

Variable	T1	T2	T3	T4	Optimum Reference
Temperature (°C)	26.50 to 29.30	26.30 to 28.70	26.80 to 28.92	26.30 to 27.68	25 to 30 ºC (Siqwepu *et al.*, 2020)
DO (mg L^{-1})	4.75 to 5.13	4.65 to 5.60	4.75 to 5.60	4.27 to 5.53	> 3 mg L^{-1} (Siqwepu *et al.*, 2020)
pH	7.37 to 7.52	7.90 to 8.10	7.95 to 8.10	7.85 to 8.03	6.5 to 8 (Siqwepu *et al.*, 2020)
TSS (mg L^{-1})	4.67 to 5.44	4.40 to4.56	4.06to 4.45	4.00to 4.56	< 80 (Siqwepu *et al.*, 2020)
TAN (mg L^{-1})	0.15 to 0.47	0.15 to 0.27	0.15 to 0.27	0.15 to 0.25	< 0.27 (Elesho *et al.*, 2021)
NO_2-N (mg L^{-1})	0.05 to 0.35	0.05 to 0.31	0.05 to 0.27	0.05 to 0.24	< 0.21 (Elesho *et al.*, 2021)
NO_3-N (mg L^{-1})	14.64 to 49.67	14.64 to 47.60	14.64 to 43.28	14.64 to 45.27	< 53 (Elesho *et al.*, 2021)
PO_4-P (mg L^{-1})	0.65 to 9.96	0.65 to 8.85	0.65 to 8.63	0.65 to 8.51	< 10 (Elesho *et al.*, 2021)

Figure 1 shows the trend of nutrient removal efficiency every 7 d for each treatment. The removal efficiency of NO_3 and PO_4 in all treatments tended to increase every week, except at T3 (250 g m^{-2}) that the removal of phosphate decreased at 2nd wk and nitrate at 4th wk. The TAN removal efficiency for all treatments was almost the same level at week two, and then in the following week, it tended to increase. On the other hand, NO_2 removal efficiency fluctuated for all treatments.



PHOSPHATE-P NITRATE-N

Figure 1. Nutrient Removal efficiency (%) Phosphate-P (A), Nitrate-N (B), Nitrite-N (C) and Total Ammonia Nitrogen TAN (D)

3.1.2. *Catfish growth performance*

The growth performance of catfish fry consisting of survival, specific growth rate, absolute length, total feed consumption, and feed conversion on maintenance for 30 d is presented in Table 2. The statistical analysis of results showed that Treatments, T3 and T4 almost significantly differences between treatments ($P < 0.05$) varied from other treatments, except for survival, which was not significantly different. But only absolute length of fishes of T4, T3 and T2 had significant ($P < 0.05$) difference from that of T1. (*E. palaefolius*, 350 g m^{-2}) showed the highest value for specific growth and absolute length and the lowest feed conversion rate.

Table 2. Growth performance of catfish cultured under aquaponics system

Variable	T1	T2	T3	T4
Specific growth rate (%)	2.53±3.74^{b}	3.18±5.54^{b}	3.84±4.93^{a}	4.00±2.73^{a}
Absolute length (cm)	3.06±0.46^{b}	4.57±0.16^{a}	4.66±0.16^{a}	4.72±0.15^{a}
Feed consumption (g)	106.53±4.23	173.63±2.63	158.40±6.39	165.83±5.06
Feed conversion ratio	0.54±0.8^{b}	0.43±0.02^{b}	0.39±0.02^{a}	0.35±0.01^{a}
Survival rate (%)	100.00±0.00	100.00±0.00	100.00±0.00	100±0.00

The different letters in each row showed significant differences ($P < 0.05$)

3.1.3. Plant growth performance

The statistical analysis results showed significant differences of plant growth parameters of T4 and T3 had significant ($P < 0.05$) differences from the same of T1 but not in the case of plant height. The T4 (350 g m^{-2}) had the highest biomass gain, daily growth, nitrogen retention and phosphorus retention. Meanwhile, plant height was not significantly different.

Table 3.Plant growth performance (*E. palaefolius*)

Variable	T2	T3	T4
Δ biomass (g)	84.67±5.25^{a}	109.67±2.60^{b}	112.67±2.89^{c}
Daily growth (g)	2.07±0.07^{a}	3.37±0.49^{b}	4.97±0.83^{c}
Plant height (cm)	20.48±3.56	29.25±1.79	48.97±4.53
Nitrogen retention (g)	99.87±4.39^{a}	143.84±0.74^{b}	178.11±6.53^{c}
Phosphorus retention (g)	68.23±3.62^{a}	121.43±0.39^{b}	149.12±1.64^{c}

The different letters in each row showed significant differences ($P < 0.05$)

3.2. Discussion

The maintenance of catfish fry by applying aquaponics technology was greatly influenced by environmental factors, including temperature, pH, and dissolved oxygen. The higher the temperature of the media was, the higher the metabolic rate of the fish was so that the fish appetite increased, which means an increase in the toxicity of excreted metabolic waste. The range of temperatures in this study was still in good condition for catfish growth (26.30 ºC to 28.92 ºC). According to Siqwepu *et al.* (2020), the optimal temperature ranged for catfish is 25 ºC to 30 ºC. Elesho *et al.* (2021) support that catfish can grow well at 25 ºC to 31 ºC.

The pH value during the observation period ranged from 7.37 to 8.10. This pH value was in the optimum range of catfish growth, accounting for 6.5 to 9 (Ajiboye *et al.*, 2015; Hasan *et al.*, 2020). Moreover, dissolved oxygen in this study ranged from 3.8 mg L^{-1}until 7.8 mg L^{-1} (Ekawati *et al.*, 2021), and this value was in the tolerance range for catfish growth, namely > 3 mg L^{-1} (Siqwepu *et al.*, 2020). Meanwhile, according to Elesho *et al.* (2021), dissolved oxygen for catfish must be above 4 mg L^{-1} which has the similarity with the present findings.

During the present study, it was found that TSS remained still in the optimal range, supporting catfish survival and plant growth. The optimal range of TSS values was 25 mg L^{-1} to 80 mg L^{-1} (Oseni *et al.*, 2018). The high TSS value could inhibit the growth of aquatic plants because it interferes with the plant's photosynthetic process. According to Sanjoto *et al.* (2020), suspended and dissolved materials in the water are not toxic. However, if they are in excessive amount, they can increase the turbidity value, further inhibiting sunlight penetration into the water column and ultimately affecting the photosynthetic process in the water (Oseni *et al.*, 2018).

In this study, the measured ammonia was one of the part of total ammonia nitrogen (TAN). The TAN value ranged from 0.15 mg L^{-1} to 0.47 mg L^{-1} (Table 1), lower than the research of (Akinbile and Yusoff, 2012), which used *Eichhornia crassipes* Martand, *Pistia stratiotes* L. as remediating agents. The results of TAN, NH_3 and NH_4 shown ranged from 1.34 mg L^{-1}, to 1.79 mg L^{-1}; 0.14 mg L^{-1}, to 0.2 mg L^{-1} and 0.13 mg L^{-1}, and 0.22 mg L^{-1}, respectively.

The water quality in the phytoremediation-based recirculation system was optimal because plants could utilize fish culture waste as nutrients for their growth. According to Effendi *et al.* (2015), water spinach can reduce TAN by 84.6 %, 34.8 % of NO_3 and 44.4 % of PO_4. On the other hand, Delis *et al.* (2015) reported that Vetiver grass [*Chrysopogon zizanioides* (L.) Roberty] could reduce TAN by 48.36 % and PO_4 by 19.94 %. In this study, the ability of *E. palaefolius* was the highest in reducing TAN, NO_2, $NO_{3,}$ and PO_4 by of T4. The percentage of removal of TAN, NO_2, NO_3, and PO_4 on 28th d was 23.80 %; 48.91 %; 52.99 %; and 27.63 %, respectively. Meanwhile, the lowest nutrient removal by of T1, were TAN on 14th d was 9.8 %; while NO_2 on 7th d was 19.07 %; NO_3 on 7th d was 19.97 %, and PO_4 was 11.05 % on 7th d. Plants as phytoremediators utilize ammonium and nitrate, where the primary source of inorganic nutrients came through plant roots (Enduta *et al.*, 2011), while it is not toxic for fish. When the water conditions are sufficiently oxidized, ammonia will be converted into an intermediate product, namely nitrite (NO_2).

Nitrite is a relatively unstable compound because, with sufficient oxygen, it will be easily oxidized to nitrate by *Nitrobacter*. The nitrite concentration in this research could still be within tolerable levels by fish, although it increased because this compound is unstable. Their changes in the system could be overcomed with sufficient oxygen supply so that the eels can still grow well. According to Van Rijn (2013), in the circulating system, the nitrite concentration should not exceed 10 mg L^{-1} for an extended period, and in most cases it should remain below 1 mg L^{-1}. According to Elesho *et al.* (2021), nitrite concentration must be < 0.21 mg L^{-1} in water media. The *Nitrobacter* bacteria then oxidizes nitrite (NO_2) to produce nitrate (NO_3).

Furthermore, nitrate is the end product of the nitrogen cycle and a compound that is not harmful to fish and a source of nutrients for plants other than NH_4. The nitrate concentration in this study was still supportive for catfish life because it ranged from 14.64 mg L^{-1} to 49.67 mg L^{-1}. The research results by Elesho *et al.* (2021) on the rearing system of catfish, NO_3 was 53 mg L^{-1}, while Jaeger *et al.* (2019) recommended that the NO_3 concentration not exceed 50 mg L^{-1} in waters used for fish farming. High concentrations of NO_3 can result in algae blooms which cause a decrease in pH (Ebeling *et al.*, 2006; Nuwansi *et al.*, 2019). Morning glory (*Ipomoea aquatica* Forssk.) can reduce total ammonia - nitrogen N, nitrite-N, nitrate-N and orthophosphate significantly from 78.32 % to 85.48 %, 82.93 % to 92.22 %, and 79.17 % to 87.10 %, respectively, and 75.36 % to 84.94 %, whereas by using Chinese broccoli (*Brassica oleracea* var. *alboglabra* L.), total ammonia nitrogen could be reduced from 75.85 % to 69.0 %, 79.34 % to 72.49 % for nitrite-N, 80.65 % to 66.67 % for nitrate-N and 77.87 % to 66.79 % for orthophosphate (Enduta *et al.*, 2011).

The survival rate in this study was 100 %. This result was higher when compared to the study by Okomoda *et al.* (2020) where catfish maintained in a settling tank and aerobic tank as filters gave a survival rate of 82.78 %. According to Enduta *et al.* (2011), the survival rates of African catfish (*C. gariepinus*) treated with aquaponics technology using kale (*Brassica oleracea* var. *sabellica* L.) and caisim (*Brassica rapa* L. Cv. group Caisin) plants were 94.5 % and 94.2 %, respectively. Based on the growth performance data of catfish (Table 2), the density of *E. palaefolius*plants as a phytoremediation agent in catfish culture with recirculatory aquaponics affected the growth performance of catfish significantly ($P < 0.05$). The T4 showed the highest growth performance for catfish, including a specific growth rate of 4.00 %, an absolute length of 4.72 cm, and feed conversion of 0.4. This was due to utilizing nutrients from the highest level of catfish culture waste at T4. Therefore, the water quality conditions for catfish rearing were still in good condition to utilize feed more efficiently. According to Pedersen *et al.* (2012), recirculation application of recirculatory system with water plants, duck weeds (*Lemna gibba* L), dropped FCR value, increased protein efficiency ratio, and tilapia growth. The FCR in fish farming must be considered because it would affect the cost of feed. Small changes in FCR would have a big effect on the profitability of cultured fish (Liu *et al.*, 2016).

The success of the aquaponics system was inseparable from the growth of *E. palaefolius*. During the observation period, the development of aquatic ornamental plants showed a positive response to the aquaponics system. That indicated an increase in biomass growth in all treatments and nitrogen retention in plant tissues (Table 3). Freshwater ornamental plants could utilize waste of catfish cultivation waste as a sources of nutrients for their growth. This was evidenced by an increase in the percentage of nutrient removal by plants every 7 d (Figure 1). The results of biomass growth, daily growth, plant height, nitrogen retention, and phosphorus retention were the highest in T4 with successive values: 112.67 g, 4.97 %, 48.97 cm, 178.11 g, and 149.12 g, respectively.

4. Conclusion

Based on our findings, *E. palaefolius*has a high potential as a water remediator, proved in *C. gariepinus* growth performance, nutrient removal capabilities and water quality data. The highest value of those measurements was obtained at 350 g m^{-2} density of *E. palaefolius*. Moreover, the present results indicated that the higher density of *E. palaefolius* showed a better impact on *C. gariepinus* development, nutrient removal, and water quality. Hence, further research is still needed for investigating the optimum density of *E.* palaefolius before it can be used in *C. gariepinus* culture or other fish commodities.

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