

Research Article

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Comparison of total nutrient recovery in aquaponics and conventional aquaculture systems

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Abstract

Introduction – More eco-friendly aquaculture technology is required to reduce environmental pollution which has become a major issue in aquaculture industries in the last few decades. Aquaponics system is a culture technology to solve this waste issue. Thus, this study aimed at comparing growth performances, feed utilization efficiency, and nutrient recovery in aquaponics and conventional aquaculture system.

Materials and methods – Twenty-four juveniles of Nile tilapia (*Oreochromis niloticus*) weighing 1.12 ± 0.1 g were cultured in either aquaponics systems or conventional aquaculture systems for 30 days. Each system had three culture systems as replicates. The fish were fed the same amount with a commercial pellet three times a day.

Results – The result showed that the Nile tilapia reared in the aquaponics system had a significantly higher specific growth rate than that of fish reared in the conventional system, 7.5 and 6.3% BW/day, respectively. Similarly, the feed utilization efficiency of fish reared in the aquaponics was also significantly better than that of fish in the conventional system. Furthermore, the total biomass harvested from the aquaponics system was nearly eight times higher than the total biomass harvested from the conventional system.

Conclusion – Growth, feed utilization efficiency, and total nutrient recovery in terms of biomass were higher in the aquaponics system. These results suggest that aquaponics is not only an eco-friendly aquaculture system, but also could produce more biomass than a conventional aquaculture system, and therefore, could be scaled up in a commercial scale.

Keywords: aquaponics, feed utilization, growth, tilapia

1 Introduction

Aquaculture waste has become a major issue in aquaculture industries in the last few decades. Lupatsch and Kissil [1], for instance, predicted that only 22% of nitrogen and 29% of phosphorus in feed were taken up by fish as growth. However, 17% of feed nitrogen and 52% feed phosphorus were excreted as feces. Ten percent of the feed nitrogen and 44% of the phosphorus feed were accumulated in sediments, while the rest of feed nitrogen was dissolved as ammonia-bound nitrogen released via the gills and phosphorus was secreted through urine as orthophosphate in the water column. In a conventional aquaculture system, such aquaculture waste is discharged into the environment without any treatment. Cao et al. [2] reported that the discharge of aquaculture waste could result in a remarkable increase of organic matter which later deteriorated water quality and eutrophication, the excessive growth of phytoplanktons leading to imbalances in primary and secondary productivity [3]. To avoid such issue, eco-friendlier aquaculture systems have been developed including autotrophic biofloc technology [4] and aquaponics system.

Aquaponics is an aquaculture system that combines recirculation aquaculture systems and hydroponics (plant production in water without soil) in a closed-loop system [5]. The main mechanisms in aquaponics are the conversion of aquaculture waste (NH_3) produced by the fish into nitrate (NO_3) which later can be used to grow plants [6].

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Aquaponics has been practised in several countries including South Africa [7], Brazil [8], and United States [9] due to being considered as an eco-friendly aquaculture system and producing more products (fish and vegetables). In addition, Al-Hafedh et al. [10] stated that an aquaponic system used less water to produce the same amount of fish biomass than a conventional aquaculture system. Later, it was confirmed that the aquaponic system used less water due to its ability to reuse water continuously and waste dissolved in the rearing water could be converted to nutrient to grow vegetables [5,6].

However, the use of aquaponics system in some countries including Indonesia is mostly still on a laboratory scale. This might be because the study of an aquaponic system is still very limited, thus the entrepreneurs still doubt about the application of this technology in commercial scales. A study of the aquaponic system in Indonesia conducted by Susila et al. [3], for example, was only focused on a model developed to reduce organic waste. While other important factors, such as the growth of cultured fish and feed utilization rate, are still neglected. Thus, the present study investigated the growth performances and feed utilization efficiency of Nile tilapia reared in two different aquaculture systems, an aquaponics system and a conventional aquaculture system. The major aim was to provide more data on the growth performances, feed utilization efficiency, and total nutrient recovery in an aquaponic system compared to a conventional aquaculture system as the control. The study was performed by culturing tilapia juvenile in the two systems for 30 days and feed with commercial pellets. At the end of the experimental period, specific growth rate (SGR), nutrient utilization efficiency, and total harvested biomass were calculated and compared between the systems. It was expected that the study result can be used as additional data sources to develop more sustainable aquaculture practices in future.

2 Materials and methods

2.1 Experimental design

This study used a completely randomized design with two treatments (aquaponics vs conventional aquaculture system), of which three replicates units have been applied. Each replicate was placed randomly to have the completely randomized experimental design, as presented in Figure 1. The experiment was performed for 30 days, and at the end of the experiment (day 31), several parameters,

including the final weight, final harvested biomass, nutrient utilization efficiency, and proximate compositions of fish, were analyzed and compared between treatments.

2.2 Preparation of aquaponics system

Three units of aquaponics systems and three units of conventional aquaculture system were used in the present study. Each unit of the aquaponics system consisted of a 25 L rearing tank, 20 L waste treatment tank, and four polyvinyl chloride (PVC) for hydroponic system connected in series (Figure 1). The rearing tank was equipped with a ceramic air diffuser connected with an air pump. All tanks were first filled with well water, disinfected with chlorine, followed by a neutralization process by adding sodium thiosulfate as previously described by Amin et al. [11]. After 24 hours, biofilter bag containing 100 bio-ball (diameter of 10 cm) was placed above the air diffuser. With continuous aeration, 2 L of pond water was filled into each waste treatment tank. Then, ammonium chloride (NH_4Cl) was added to have an ammonia concentration of ~ 3 mg/L. After ammonia concentration was less than 0.05 mg/L (\sim days), the rearing tank was stocked with 24 Nile tilapia with an average weight of 1.12 ± 0.1 g. The Nile tilapia were slowly acclimated for one week. Any dead fish was replaced with the new fish. The experiment began when there was no dead fish for one week. Then, Nile tilapia were fed four times daily (8 a.m., 11 a.m., 2 p.m., and 5 p.m.) at satiation level for 5 min with a commercial diet containing 41% crude protein (CP; PRIMA). To compensate for water loss due to evaporation, well freshwater was passed through three series of filters (1, 0.5, and 0.3 μL) and was added to the tanks. Mustard green (*Brassica juncea*) was seeded on a 3 cm \times 3 cm Rockwool individually and watered daily. After 24 hours, the seeds began to sprout and grow for ~ 5 days. Subsequently, 48 mustard green sprout weighing 3.9 ± 0.9 g were transferred to each unit of the aquaponics system.

However, conventional aquaculture system consisted of three rearing units of 25 L rearing tanks (the same volume as the rearing unit of the aquaponic system). Rearing water was replaced by 25% of total volume daily to maintain optimal water quality parameters for tilapia juveniles. Flowchart of the present study is presented in Figure 2

Ethical approval: The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

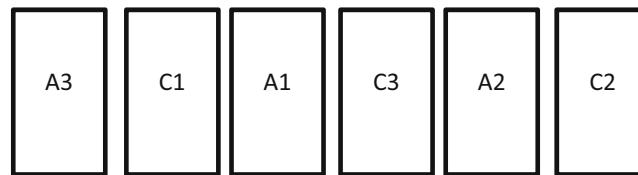


Figure 1: Experimental design and the placement of rearing units. Ax: aquaponic system with an x replicate unit, Cx: conventional aquaculture system with an x replicate unit.

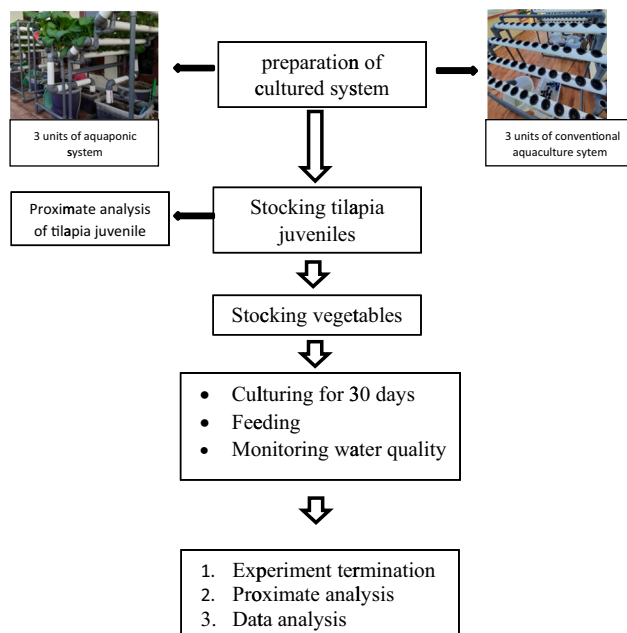


Figure 2: Flowchart of the experiment started from the preparation of cultured systems until experiment termination and data analysis.

2.3 Water quality

Physicochemical water parameters were monitored at a safe level for tilapia juvenile during the experiment. Dissolved oxygen (DO) and temperature were measured daily (DO meter, Lutron). The analysis of pH (pH meter, AS218), ammonia (Handled Colorimeter Ammonia MR HI715, Hanna Instrument), nitrite (Handled Colorimeter Ammonia HR HI708, Hanna Instrument), and nitrate (HANNA HI 96786 Nitrate Portable Photometer) were analyzed once a week.

2.4 Measured variables

After the experimental period, the following performance indexes of Nile tilapia were evaluated using a formula previously described by Amin *et al.* [11]. These parameters are the most common parameters to measure

because of their capacity to represent the productivity of a cultured system:

- $SR (\%) = \left(\frac{\text{Final number of animals}}{\text{Initial number of animals}} \right) \times 100$
- $WG (g) = \frac{(\text{Average final weight} - \text{Average initial weight})}{\text{Days of culture}}$
- $SGR (\% BW/\text{day}) = \frac{(\ln(W_t) - \ln(W_0) \times 100)}{t}$

SR: Survival rate, WG: weight gain. “*t*” is the culture period in days, “ $\ln W_0$ ” is the natural logarithm of the weight of the Nile tilapia at the beginning of the experiment and “ $\ln W_t$ ” is the natural logarithm of the weight of the Nile tilapia at day “*t*”.

- $FCR = \frac{\text{Feed intake (g)}}{\text{Biomass gain (g)}}$
- Final biomass (g/tank) = total biomass harvested per tank
- Feed intake (g/tank) = total amount of feed added per tank

FCR: feed conversion ratio.

2.5 Body composition

CP, crude fat, and the energy content in fish, feces, pellet, and vegetables were determined according to a protocol of AOAC International (2005). In brief, samples of fish or feces were placed into an oven with a temperature of 100–102°C for 2 h. The samples were then taken out and placed into a desiccator for 60 min. and weighed. After weighing, the samples were placed back into the oven for 1 h; afterward, the samples were placed back to the desiccator prior to weighing. The repetition was stopped when there was at least 0.1 mg difference in the weight. Thereafter, the known amount of dried samples was put in a porcelain and put in a muffle furnace at 550°C. After 3 h burning, the sample was taken out and put directly in a desiccator. The sample was weighed and put again into the muffle furnace until a constant weight was achieved (0.1 mg difference). While the CP content was analyzed using the Kjeldahl method, fat content was measured using a Berntrop procedure as previously described by Amin [12].

2.6 Feed utilization efficiency

To measure the feed utilization efficiency, data of proximate analysis were used to calculate protein efficiency ratio (PER), fat efficiency ratio (FER), and energy efficiency ratio (EER) according to the formula previously described by Amin et al. [13].

$$\begin{aligned} \bullet \text{ PER} &= \frac{(W_t - W_0)}{(F \times P_F)} \\ \bullet \text{ FER} &= \frac{(W_t - W_0)}{(F \times F_F)} \\ \bullet \text{ EER} &= \frac{(W_t - W_0)}{(F \times E_F)} \end{aligned}$$

Where: W_t : final weight, W_0 : initial weight, F : total feed consumed, P_F : protein content in the feed, F_F : fat content in the feed, and E_F : energy content in the feed.

2.7 Data analysis

Data of initial weight, final weight, weight gain, SGR, survival rate, crude fat, crude energy, and feed conversion ratio were presented as mean value \pm standard deviation. Then, these values were compared using analysis of independent t -test, at $p < 0.05$ with SPSS software version 23 after fulfilling three common assumptions, independent, normal distribution (Kolmogorov Smirnov, $p > 0.05$), and equal variance (Levene test, $p > 0.05$).

3 Results

3.1 Growth performances

Nile tilapia juveniles were cultured in either aquaponics system or conventional aquaculture system for 30 days. At the beginning (day 1), the weight of tilapia juvenile stocked to the aquaponics system was not significantly different from the weight of tilapia juvenile stocked in the conventional aquaculture system ($t = 0.09$, $df = 4$, $p = 0.93$). However, the final weight of fish reared in the aquaponics system was significantly higher than that of fish reared in the conventional aquaculture system after a 30-day culture period ($t = 6.73$, $df = 4$, $p = 0.003$; Table 1).

Similarly, weight gain, SGR, and total harvested biomass were also significantly higher in the fish reared in the aquaponics system than that of fish reared in the

Table 1: The performance index of Nile tilapia reared in the aquaponics system and conventional aquaculture system for 30 days

Performance index	Average \pm Stdev	
	AS	CAS
Initial weight (g)	1.06 \pm 0.05 ^a	1.07 \pm 0.04 ^a
Final weight (g)	10.29 \pm 0.81 ^B	6.63 \pm 0.47 ^A
Weight gain (g)	9.31 \pm 0.76 ^Y	5.60 \pm 0.50 ^x
SGR (% BW/day)	7.46 \pm 0.04 ^Y	6.25 \pm 0.30 ^x
SR (%)	91.67 \pm 2.89 ^z	90.00 \pm 5.00 ^z
Feed intake (g/indv)	9.68 \pm 0.23 ⁿ	7.53 \pm 0.77 ^m
FCR	0.96 \pm 0.06 ^N	1.34 \pm 0.02 ^M
Total harvested biomass (g)		
Fish	205.76 \pm 16.28 ^q	132.57 \pm 9.46 ^P
Vegetables	1,475.49 \pm 304.38 ^b	0

SGR: specific growth rate, SR: survival rate, FCR: feed conversion ratio, AS: aquaponics system, CAS: conventional aquaculture system. Values are average with a standard deviation of three-unit replicates. Different superscripts indicate a significant difference at $p < 0.05$.

conventional aquaculture system, $p < 0.05$. However, feed intake of fish reared in the aquaponics system was significantly different from that of fish reared in the conventional aquaculture system, $p < 0.05$. In addition, the feed conversion ratio of fish cultured in the aquaponics system was significantly better than that of fish cultured in the conventional aquaculture system ($t = 10.39$, $df = 4$, $p < 0.001$). But there was no significant difference in survival rate between fish at the aquaponics system and the conventional aquaculture system, all SR $> 90\%$ ($t = 0.50$, $df = 4$, $p = 0.64$).

Furthermore, total fish biomass harvested from the aquaponics system was significantly higher than that of fish reared in the conventional aquaculture system, $p < 0.05$. As presented in Table 1, total fish biomass harvested from the aquaponics and the conventional culture system were 205.76 \pm 16.28 g and 132.57 \pm 9.46 g, respectively. Besides harvesting fish, the aquaponics also produced 1,475.49 \pm 304.38 g mustard green.

3.2 Body composition of harvested fish

The proximate compositions of fish harvested from the aquaponics and conventional system are presented in Table 2. The result showed that there was no significant difference in all measured parameters: dry matter, ash, CP, crude fat, and energy contents of fish (all $p_{\text{values}} > 0.05$).

Table 2: Proximate composition of fish reared in either the aquaponics system or conventional aquaculture system for 30 days

Performance index	Average \pm Stdev	
	AS	CAS
Dry matter (%)	22.26 \pm 1.84 ^a	21.50 \pm 2.59 ^a
Crude protein (%)	12.59 \pm 0.11 ^a	13.93 \pm 0.75 ^a
Crude fat (%)	9.66 \pm 3.86 ^a	12.28 \pm 3.09 ^a
Carbohydrate (%)	5.70 \pm 0.47 ^b	5.30 \pm 0.25 ^a
Energy (J/g)	784.18 \pm 296.77 ^a	768.40 \pm 92.78 ^a
Ash (%)	1.49 \pm 0.41 ^a	3.15 \pm 1.21 ^a

AS: aquaponics system, CAS: conventional aquaculture system. Values are the average and standard deviation of triplicates. The same superscript indicates they were not significantly different ($p > 0.05$).

3.3 Feed utilization efficiency

There were significant differences in feed utilization efficiency of fish reared in the aquaponic system and conventional aquaculture system (Table 3). PER was significantly higher in fish biomass harvested from the aquaponics system than in the conventional aquaculture system ($t = 26.67$, $df = 4$, $p < 0.001$). The same result was observed from FER and EER, in which FER and EER were also significantly higher in fish harvested from the aquaponics system compared to fish obtained from the conventional aquaculture system (all $p_{\text{values}} < 0.001$).

3.4 Water quality

All measured parameters of physicochemical water quality in all rearing tanks were in the normal range for Nile tilapia (Table 4). Average values of temperature, DO, ammonia, and pH were not significantly different in the

Table 3: Feed utilization efficiency of fish reared for 30 days in the different aquaculture systems

Feed utilization	Average \pm Stdev	
	AS	CAS
Protein efficiency ratio (%)	2.69 \pm 0.03 ^b	1.79 \pm 0.05 ^a
Fat efficiency ratio (%)	26.76 \pm 0.35 ^b	17.77 \pm 0.46 ^a
Energy efficiency ratio (%)	0.11 \pm 0.001 ^b	0.07 \pm 0.002 ^a

AS: aquaponics system, CAS: conventional aquaculture system. Values are the average and standard deviation of triplicates. The different superscript indicates they are significantly different at $p < 0.05$.

Table 4: Physicochemical water quality parameters (temperature, DO, ammonia, nitrite, nitrate, and pH) measured in the rearing water of aquaponic system and conventional aquaculture system

Parameters	Average \pm Stdev	
	AS	CAS
Temperature ($^{\circ}\text{C}$)	28.75 \pm 0.25 ^A	27.56 \pm 0.64 ^A
DO (mg/L)	5.89 \pm 0.14 ^P	5.46 \pm 0.46 ^P
Ammonia (mg/L)	0.99 \pm 0.40 ^a	0.42 \pm 0.13 ^a
Nitrite (mg/L)	0.29 \pm 0.11 ^Y	0.07 \pm 0.00 ^X
Nitrate (mg/L)	15.06 \pm 1.25 ^N	0.30 \pm 0.06 ^M
pH	7.96 \pm 0.06 ^P	7.44 \pm 0.32 ^P

DO: dissolved oxygen, AS: aquaponics system, CAS: conventional aquaculture system. Values are the average and standard deviation of triplicates. Values with the different superscript indicated that there was a significant difference at $p < 0.05$.

rearing water of both system, all $p_{\text{values}} > 0.05$. However, nitrite and nitrate concentrations were significantly higher in aquaponic system than those of conventional aquaculture system ($t = 20.51$, $df = 4$, $p < 0.01$ and $t = 3.53$, $df = 4$, $p = 0.024$ for nitrite and nitrate, respectively). Water quality in the conventional system appeared to more fluctuate, especially ammonia concentration.

4 Discussion

The present study compared the feed utilization efficiency and growth performances of Nile tilapia at a juvenile stage when they were cultured in an aquaponic system and conventional aquaculture system for a 30-day culture period. The result, in general, showed that Nile tilapia reared in the aquaponic system had better growth performances and were more efficient in nutrient utilization compared to those fish reared in the conventional aquaculture system. This result is consistent with that of previous studies by several authors using aquaponics regardless of their species and life stage of species. In term of growth, SGR calculated from the fish harvested from the aquaponics system was 1.2% higher, 7.5% vs 6.3% BW/day for the aquaponics vs conventional system, respectively. The lower SGR of fish obtained from the conventional system might relate to the lower feed intake in the fish of the conventional system. However, the lower feed intake was caused due to less appetite since the fish in both aquaculture systems were fed at satiation level. However, it was unclear which factor causes the lower appetite because water quality parameters, in general, were not significantly different except nitrite.

According to Monsees et al. [14], the nitrite levels in the rearing water of both systems were still below a toxic level for tilapia, <500 mg/L.

SGRs obtained in this present study were higher than the SGR of tilapia juvenile in previous studies. Hussein et al. [15], for instance, reported SGR of Nile tilapia fed with 37% CP of formulated diet which was 3–5% BW/day. An almost similar result was reported by Sarker et al. [16], which was 3.5% BW/day, and by Qiang et al. [17], which was ~3% BW/day. The SGRs obtained from both systems were also higher than what has been previously reported by Azaza et al. [18], ~5–6%. These results may indicate that the rearing environment in both the aquaponic system and the conventional system was in optimal conditions for the Nile tilapia to growth. Similarly, the PER in the fish reared in the aquaponics system was also significantly better than in the fish reared in the conventional system, 2.7 vs 1.8 for aquaponic and conventional system, respectively. The average value of PER in fish culture in both systems in the present study was also higher than previously reported by Hussein et al. [15], which was ~1.08. This study result is another proof to support that environmental condition at which the fish were cultured in the present study was in optimal ranges for the tilapia.

The present study also showed that the total biomass harvested from the aquaponic system was significantly higher than the conventional system. As presented in Table 1, the total biomass from fish harvested from aquaponics was almost double the total biomass of fish biomass harvested from the conventional system, 205 g vs 132 g, respectively. When the total vegetables (~1.5 kg) were included, total biomass harvested from the aquaponics become 1.7 kg, which was much higher compared to the conventional system. This result suggests that the aquaponic system is very efficient in harvesting nutrient from the feed. This result also confirms a previous study by Licamele [19] where an aquaponic system could produce 308 g/m² lettuce (*Lactuca sativa*) from every 100 g feed given to the fish reared in an aquaponics aquaculture system. However, this study could produce ~638 g vegetable from every 100 g of feed in the aquaponics, which is higher than the study by Licamele [19].

This study results contribute by giving additional evidence on several advantages which can be obtained by culturing fish using aquaponics system. We proved that SGR, nutrient utilization efficiency, and total biomass production were higher in fish reared in the aquaponics system compared to that of conventional culture system. The aquaponics system can produce more biomass than the conventional aquaculture system. However, this study

should be continued by investigating the economic aspects. We showed that the aquaponic systems can be competitive with current commercial conventional aquaculture systems. From an environmental point of view, aquaponics showed a potential alternative to conventional culture system due to its capacity to use less water and convert aquaculture waste to vegetables biomass.

5 Conclusion

Nile tilapia juvenile reared in the aquaponic system had better growth performances, feed utilization efficiency, and produced more total biomass compared to the conventional system. However, more studies should be performed in terms of economic perspective to get more comprehensive data about the aquaponics system before being applied on a commercial scale.

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Conflict of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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