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The production performance of Nile tilapia *Oreochromis niloticus* and mineral balance in aquaponic, biofloc, and aquabioponic culture systems

Kinerja produksi ikan nila *Oreochromis niloticus* serta keseimbangan mineral pada sistem budidaya akuaponik, bioflok, dan akuabioponik

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ABSTRACT

Aquaponics and bioflocs are the aquaculture systems to reduce nitrogenous waste with less water exchange. Aquaponics reduce nitrate ($NO3^-$) through the role of vegetable plants, while bioflocs assimilate ammonium ($NH4^+$) through floc-forming bacteria. In this study, a collaboration was designed between aquaponics and bioflocs, called aquabioponics. This study was conducted to evaluate the tilapia production performance and observe the dynamics of P, K, Ca, Mg, Fe, Mn, Zn, and Cu minerals in the system. A completely randomized design was applied with three treatments performed in triplicates, namely aquaponics (AP), bioflocs (BF), and aquabioponics (AB). The AP was integrated with the bok-choy culture, while BF added an organic carbon source in the fish tank. AB involved the organic carbon addition (50% of the dose used in BF) and bok-choy culture. A total of 200 Nile tilapia *Oreochromis niloticus* (initial length and weight of 5.56 ± 0.13 cm and 5.92 ± 0.47 g, respectively) were cultured in a fiber tank filled with 500 L water per treatment for 60 days. Bok-choy was harvested every 30 days. Feeding was performed at satiation three times a day (morning, afternoon, and evening). During the fish rearing, water was remained unreplaced, but water was added every 10 days to replace the water volume. Fish sampling was performed to calculate length and weight every 10 days. Aquabioponics showed the best tilapia production performance. The Ca, Mg, Mn, Zn, and Cu minerals were essential in aquaponics and aquabioponics, while Mg was important for bioflocs.

Keywords: aquaponic, aquabioponic, biofloc, minerals, nile tilapia

ABSTRAK

Akuaponik dan bioflok adalah teknik akuakultur untuk mereduksi limbah nitrogen dengan sedikit pertukaran air. Akuaponik mereduksi nitrat ($NO3^-$) melalui peran tanaman sayuran, sedangkan bioflok mengasimilasi amonium ($NH4^+$) melalui peran bakteri pembentuk flok. Penelitian ini merancang kolaborasi antara akuaponik dan bioflok yang disebut akuabioponik. Penelitian dilakukan untuk mengevaluasi kinerja produksi ikan nila, serta mengamati dinamika mineral P, K, Ca, Mg, Fe, Mn, Zn, dan Cu yang terbentuk di dalam sistem. Penelitian ini menggunakan rancangan acak lengkap dengan tiga perlakuan dan tiga ulangan, yaitu akuaponik (AP), bioflok (BF), dan akuabioponik (AB). AP mengintegrasikan penanaman sayur (pakcoy), sedangkan BF menggunakan penambahan sumber karbon organik pada wadah pemeliharaan ikan. AB menggunakan penambahan sumber karbon organik (setengah dari dosis pada BF) dan dan penanaman Pakcoy. Sebanyak 200 ekor ikan nila *Oreochromis niloticus* (panjang dan bobot awal masing-masing 5,56 ± 0,13 cm dan 5,92 ± 0,47 g) dipelihara pada bak fiber berisi 500 L air selama 60 hari pada setiap perlakuan. Pakcoy dipanen setiap 30 hari. Pemberian pakan dilakukan secara at satiation sebanyak tiga kali dalam sehari (pagi, siang, dan sore). Selama pemeliharaan ikan tidak dilakukan pembuangan ataupun penggantian air, namun dilakukan penambahan air setiap 10 hari untuk menggantikan volume air yang berkurang. Sampling ikan untuk menghitung panjang dan bobot dilakukan setiap 10 hari. Akuabioponik menghasilkan kinerja produksi ikan nila terbaik. Mineral Ca, Mg, Mn, Zn, dan Cu bersifat esensial pada akuaponik dan akuabioponik, sedangkan pada bioflok mineral yang penting adalah Mg.

Kata kunci: akuaponik, akuabioponik, bioflok, ikan nila, mineral

INTRODUCTION

Nile tilapia *Oreochromis niloticus* is a leading aquaculture commodity in Indonesia as a number one total production quantity in 2021 (1.49 million tons) and with a production value ranked second after shrimp at IDR 37.1 trillion (KKP, 2022). Intensive tilapia farming on a "land-based" pond and tank system faces several problems, especially organic waste management and clean water availability limitation, which requires a good water quality management to minimize the value of nitrogenous waste (Khanjani *et al*., 2022). Farmers need to engineer mechanisms to increase ammonia reduction in water, so they can maintain its concentration that can be tolerated by fish, because even low levels of ammonia can be toxic to most aquaculture commodities (Ebeling *et al*., 2006). Aquaponics and biofloc technology are systems that have been created as a form of water quality management solution to address the ammonia problem.

Aquaponics develop a re-circulation technique by integrating hydroponic plant culture as a filter unit to utilize liquid nitrogen in the form of nitrate (David *et al*., 2022; Roy *et al*., 2022; Spradlin & Saha, 2022; Bich *et al*., 2020; Lunda *et al*., 2019; Cohen *et al*., 2018; Bosma *et al*., 2017; Delaide *et al*., 2017; Forchino *et al*., 2017; Wongkiew *et al*., 2017). However, the solid waste of fish feces cannot be utilized properly. This is in fact different from biofloc, which plays a role in ammonia assimilation through the addition of organic carbon and utilizes fish feces as a substance for bacterial growth and floc formation (Oliveira *et al*., 2022; Bossier & Ekasari, 2017; Pérez-Fuentes *et al*., 2016; Ekasari *et al*., 2014). Nevertheless, the nitrate waste formed in biofloc remains unutilized to produce vegetable crop production.

Research conducted by Deng *et al*. (2018), Li *et al*. (2018), Luo *et al*. (2017), and Wei *et al*. (2016) showed that the biofloc system still produced nitrate in various amounts. Based on the utilization aspect of nitrate waste and fish faecal waste, it is possible that aquaponics and biofloc can be combined to optimize the water quality management. Based on the combination of aquaponics and biofloc, a new term can be created, namely "Aquabioponics", which is expected to be a solution for increasing the land-based tilapia aquaculture.

MATERIALS AND METHODS

Design

The study was performed in the research facility of Aquaculture Production Technique and Management Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University. The experiment used completely randomized design with three treatments in triplicates (nine experimental units), namely aquaponics (AP), bioflocs (BF), and aquabioponics (AB). The aquaponic system reared the fish, integrated with vegetable culture. Biofloc system reared the fish with organic carbon source addition. Aquabioponic system combined aquaponics and bioflocs by integrating vegetable culture and organic carbon source addition at half dose of the biofloc system. The organic carbon addition in AB at half dose of BF was aimed to balance two nitrogen conversion process by autotrophic bacteria (nitrification) and floc-forming heterotrophic bacteria (Ebeling *et al*., 2006).

Fish rearing media preparation

A rounded fiber tank with 120 cm diameter and 60 cm height was used for fish rearing and filled with water at 44.19 cm height (500 L). In AP and AB treatments, water from the rearing tank was connected to the vegetable culture and filter tube. The vegetable culture media were five units of PVC box, that were organized vertically with 15 cm distance. Each box had 60 cm length, 10 cm width, 5 cm height, and six holes as planting sites, thus there were 30 sites in one system. The fiber filter tube with 20 cm diameter and 50 cm height was filled with 560 g of *Kaldness Micro* (Figure 1). Two water pumps (Pump 1: 60 watt, 3000 L/hour; Pump 2: 23 watt, 900 L/hour) were used as a connector among the fish rearing medium, vegetable culture, and filter tube, thus producing a water circulation for 24 hours a day.

Before the fish rearing was performed, the rearing media was chlorinated, followed by fertilization and mineral salt enrichment. Chlorination was performed as a disinfection with sodium hypochlorite (NaOCl) solution with 10% active ingredients at 30 ppm. The chlorinated water was aerated until the chlorine concentration turned to 0 ppm (safe for bacterial growth, expected for fertilization). This process was occurred for 14 days. Fertilization and mineral salt enrichment were composed of ammonium bicarbonate (NH_4HCO_3), sodium nitrite ($NaNO_2$), *Sanolife Pro-W* (*Inve Technologies, Belgium*) commercial probiotics, tapioca flour, P-K macro compound fertilizer (52% P_2O_5, 34% K_2O), calcium nitrate fertilizer (15.5% N, 26% CaO), Mg-S macro compound fertilizer (16% MgO, 13% S), and micro compound fertilizer (2.5% Fe, 7% Mn, 5% Zn, 2% Cu) (Table 1).

Fertilization was performed to supplement the nitrogen source, thereby accelerating the floc formation (in BF and APBF treatment) and bacterial growth that plays a role in nitrification and nitratation processes (in AP and APBF treatments). The mineral salt enrichment was performed to elevate the initial concentration of P, K, Ca, Mg, Fe, Mn, Zn, and Cu minerals in the rearing media. These materials were used based on the water quality standard for fish culture in Indonesia, following the Indonesian Ministry of Health Regulation of 492/MENKES/PER/IV/2010 about the drinking water quality requirement (Permen, 2010). This regulation was applied to clarify that the minerals were non-toxic for fish. Mineral salt enrichment was also performed for 14 days, until the ammonia solution in the water was among 0 – 0.5 mg/L, before stocking was performed.

Fish rearing and vegetable culture

Tilapia (*Oreochromis niloticus*) with 5.56 ± 0.13 cm and 5.92 ± 0.47 g, were reared at a stocking density of 400 individuals/m^3. These fish were fed with commercial floating feed *PF-1000* with 1.3-1.7 mm size, 41.12% protein, 6% carbohydrates, 2.72% fat, and 2.53% fiber. Fish were fed at satiation three times a day (morning, afternoon and evening), and the consumed feed was recorded every day. In the BF and AB treatments, organic carbon (tapioca flour) was stocked every morning, following the total feed intake from the previous day. Dead fish were removed from the rearing container and weighed. Sampling was performed to calculate the fish length and weight every 10 days.

The water used for fish rearing in each treatment was remained unreplaced, but only adding it to the rearing tank every 10 days to increase the water volume that declined due to evaporation. The total water volume was calculated and recorded for mineral dynamics analysis occurred in each

Figure 1. Fish rearing and vegetable culture media.
Note: A = fish tank; B = vegetable planting site; C = filter tube.

Table 1. The type and amount of materials used in the fertilization and mineral salt enrichment process in each treatment.

Material (unit)	Aquaponics	Bioflocs	Aquabioponics
NH_4HCO_3 (mg)	750	1,500	1,000
$NaNO_2$ (mg)	750	-	500
Probiotics (mg)	10,000	10,000	10,000
Tapioca flour (mg)	-	185,250	61,750
P-K macro compound fertilizer (mg)	48,077	48,077	48,077
Calcium nitrate fertilizer (mg)	225,734	225,734	225,734
Mg-S macro compound fertilizer (mg)	469,750	469,750	469,750
Micro compound fertilizer (mg)	6,000	6,000	6,000

treatment. In AP and AB treatments, 30 clumps of bok-choy (*Brassica rapa*) were applied on each treatment. Bok-choy was sown to gain five leaves (10 days old), before placing it to the planting container at the same time as fish stocking. On the 30th day, harvest and replanting were carried out, thereby bok-choy planting and harvest were performed twice during the fish rearing.

Organic carbon application

The provision of organic carbon material was only performed in the BF and AB treatments. Organic carbon application by tapioca flour was divided into two stages, namely at initial fertilization and during fish rearing every day. Initial fertilization for the BF treatment used a C/N ratio of 150, while AB used a C/N ratio of 50. Daily C-organic application for the BF treatment used a C/N ratio of 10, while AB used a C/N ratio of 5. A method to calculate the amount of organic carbon materials referred to De Schryver *et al*. (2008). The formulation in determining the amount of carbon source materials for initial fertilization and daily application was:

Organic carbon formulation on the initial fertilization

$$\text{TM} = \text{C/N Ratio} \times \text{C.NH3} \times \frac{\text{MW.N}}{\text{MW.NH3}} \times \text{V.water} \times \frac{100}{\text{KCO.M}}$$

Note:
TM = Amount of organic-C addition (mg)
C/N Ratio = Applied C/N ratio
C.NH3 = Ammonia concentration in water (mg/L)
MW.N = Nitrogen molecular weight (14)
MW.NH3 = Ammonia molecular weight (17)
V.water = Water volume (L)
KCO.M = Organic-C content in materials used as organic-C source (%)

Organic carbon formulation for daily application

$$\text{TM} = \text{JP} \times \text{C/N Ratio} \times \text{KPP} \times \text{KN.pro} \times \text{KN.dn} \times \frac{100}{\text{KCO.M}}$$

Note:
TM = Amount of organic-C addition (mg)
JP = Total feed intake on the previous day (mg)
C.N Ratio = Applied C/N ratio
KPP = Protein content in feed
KN.Pro = N content in protein (0.16)
KN.dn = N withdrawal by deamination/ total undigested N ratio (0.75)
KCO.bhn = Organic-C content in materials used as organic-C source (%)

Water physiochemical quality

The physiochemical parameter in water observed in fish rearing tank was composed of temperature, pH, alkalinity, dissolved oxygen (DO), ammonia (NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and floc volume. Temperature, pH, and DO were measured every data with thermometer, pH meter, and DO meter. Alkalinity, NH_3, NO_2^-, and NO_3^- were measured on the initial rearing period and every 15 days, based on APHA (2017). Floc volume was measured on the initial rearing period and every 15 days by Imhoff cone, after the water sample was evaporated for 20 minutes.

Fish and vegetable production performance

Fish production performance contained specific length growth rate, specific weight growth rate, harvest biomass, survival rate, total feed intake, feed conversion ratio, protein retention, and system productivity. Vegetable production performance contained average weight of harvested vegetables, harvested biomass, and harvested biomass accumulation. Fish production performance parameters were calculated based on Aboseif *et al*. (2022) below:

Length gain

$$\text{LG (cm/fish): } \text{LG} = L_t - L_0$$

Note:
L_t = Final body length
L_0 = Initial body length

Weight gain

$$\text{WG (g/fish): } \text{WG} = W_t - W_0$$

Note:
W_t = Final body weight
W_0 = Initial body weight

Specific length growth rate

$$\text{SLGR (\%/ day)} = 100 \times (\ln L_t - \ln L_0)/\text{days}$$

Note:
ln = Natural logarithm
L_t = Final body length
L_0 = Initial body length

Specific weight growth rate

$$SWGR\ (\%/\ day) = 100 \times (\ln W_t - \ln W_0)/days$$

Note:
ln = Natural logarithm
W_t = Final body weight
W_0 = Initial body weight

Survival rate

$$SR\ (\%) = \frac{\text{Number of fish at final rearing period}}{\text{Number of fish at initial rearing period}} \times 100$$

Feed conversion ratio

$$FCR = \frac{\text{Feed intake (g)}}{\text{Body weight gain (g)}}$$

System productivity

$$SP\ (g/L) = (B_t + B_0 - B_d)\ /\ TWU$$

Note:
B_t = Final fish biomass (g)
B_0 = Initial fish biomass (g)
B_d = Biomass of died fish (g)
TWU = Total water used (L)

Mineral retention

Mineral mass balance was observed for P, K, Ca, Mg, Fe, Mn, Zn, and Cu minerals. Mineral content tests were carried out on water, feed, tapioca, fish, and vegetables. Water and fish mineral contents were carried out at the beginning and end of the study (60 days), while vegetable mineral content was carried out on every harvest period (30 days). The mineral content of liquid material (water) referred to APHA (2017), while mineral content of solid materials (feed, tapioca, test fish, and vegetables) referred to AOAC (2012).

Fish and vegetable mineral content tests were carried out in a composite manner, i.e. one fish or vegetable sample from each replication of the similar treatment was taken randomly and included in the proximate analysis, while the water mineral content was carried out by taking the water sample from each rearing tank. The mineral balance in each AP, BF, and AB treatments was calculated by determining the mineral retention values in fish, vegetables, and water. There are two possibilities of mineral retention, namely accumulation and reduction. If the calculation result was positive (+), then accumulation will occur, while if the result was negative (-), then reduction occurs. The retention value is the percentage of final and initial mineral content difference to the amount of input minerals derived from feed and tapioca.

Fish mineral retention

$$FMR\ (\%) = \frac{((FMC_t \times B_t) - (FMC_0 \times B_0))}{((WMC_0 \times WV_0) + (FMC \times Fin) + (TMC \times Tin))} \times 100$$

Note:
FMCt = Final fish mineral concentration
Bt = Final fish biomass
FMC0 = Initial fish mineral concentration
B0 = Initial fish biomass
WMC0 = Initial water mineral concentration
WV0 = Initial water volume
FMC = Feed mineral concentration
Fin = Feed intake
TMC = Tapioca mineral concentration
Tin = Tapioca used

Vegetable mineral retention

$$VMR\ (\%) = \frac{(VMC_t \times VB_t)}{((WMC_0 \times WV_0) + (FMC \times Fin) + (TMC \times Tin))} \times 100$$

Note:
VMCt = Final vegetable mineral concentration
VBt = Final vegetable biomass

Water mineral retention

$$WMR\ (\%) = \frac{((WMC_t \times V_t) - (WMC_0 \times V_0))}{((WMC_0 \times WV_0) + (FMC \times Fin) + (TMC \times Tin))} \times 100$$

Note:
WMCt = Final water mineral concentration
Vt = Final water volume
WMC0 = Initial water mineral concentration
V0 = Initial water volume

Data analysis

Production performance and mineral retention among treatments were analyzed through one-way ANOVA and Duncan's test, if there was a significant different. The water physiochemical quality was analyzed descriptively, presented in table and figure. Data analysis used Microsoft Excel 2016 and SPSS 25.0 softwares.

RESULTS AND DISCUSSION

Results

Physiochemical parameters

The results of physiochemical parameters in the water for 60 days, that contained temperature, pH, alkalinity, DO, ammonia, nitrite, nitrate, and floc volume, are presented in Table 2. Fluctuative DO value during the study in each treatment can be seen in Figure 2.

Fish production performance

The average length and weight growth rates of Nile tilapia in each treatment can be seen in Figure 3 and 4. The observation results on the production performance of Nile tilapia, that contained survival rate, specific length growth rate, specific weight growth rate, harvest biomass, total feed intake, feed conversion ratio, system productivity, and total water requirement, are presented in Table 3. The production performance of Nile tilapia obtained a significant difference on the specific length growth rate (P = 0.002), specific weight growth rate (P = 0.002), harvest biomass (P = 0.49), feed intake (P = 0.004), and total water requirement (P = 0.001), while no significant difference was found on the survival rate (P = 0.829), feed conversion ratio (P = 0.207), and system productivity (P = 0.163). The specific length and weight growth rates in AP and AB systems were higher than in BF system (P<0.05). The harvest biomass in AP system was significantly different from BF system (P<0.05), but showing no significant difference with AB system (P>0.05). The total feed intake in AP system was significantly different from BF and AB systems (P<0.05).

Table 2. Physiochemical parameters in Nile tilapia (*Oreochromis niloticus*) rearing water for 60 days in each treatment.

Parameter (unit)	System		
	Aquaponics	Bioflocs	Aquabioponics
Temperature (°C)	23.8 – 27	23.8 – 27.3	23.9 - 27
pH	6.61 – 8.52	6.76 – 8.49	6.76 – 8.49
Alkalinity (mg/L)	16.48 – 87.36	11.54 – 108.46	19.78 – 99.49
DO (mg/L)	1.13 – 5.80	1.57 – 5.63	1.23 – 5.80
Ammonia (mg/L)	0.01 – 1.3	0.01 – 0.05	0.01 – 1.27
Nitrite (mgL)	0.2 – 2.83	0.18 – 2.73	0.28 – 3.44
Nitrate (mg/L)	1.47 – 3.42	0.58 – 4.27	1.31 – 3.79
Floc volume (mL/L)	0	8 - 40	0

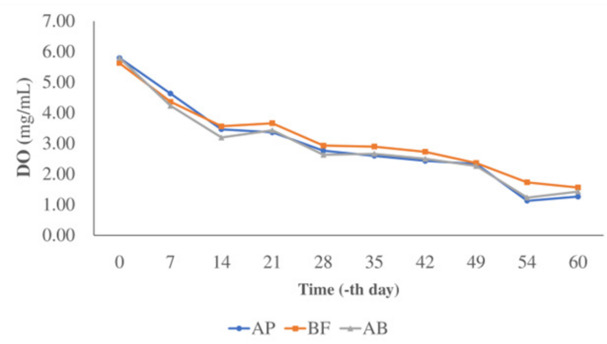

Figure 2. Fluctuative DO value during the rearing period in each treatment.
Note: AP = Aquaponics; BF = Bioflocs; AB = Aquabioponics.

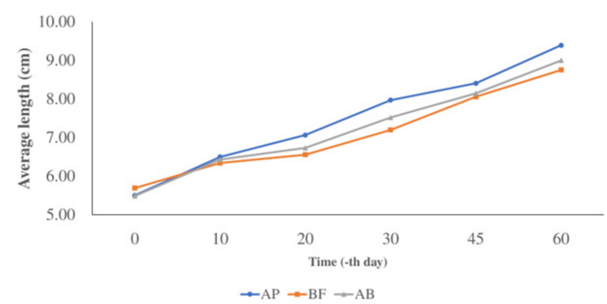

Figure 3. Nile tilapia length growth rate for 60 days.
Note: AP = Aquaponics; BF = Bioflocs; AB = Aquabioponics.

Vegetable production performance

The observation results on the bok-choy production performance for 60 days (harvested twice) in the AP and AB systems, including the (average) weight of harvested vegetables, harvested biomass, and harvested biomass accumulation, are presented in Table 4. The aquaponic system showed better results (P<0.05) than aquaponics in all production performance parameters of the bok-choy.

Mineral Retention

The results of mineral retention by fish, vegetables, and water on the AP, BF, and AB systems can be seen in Table 5. Graphs regarding mineral retention by fish, vegetables, and water in AP, BF, and AB systems, based on the P, K, Ca, Mg, Fe, Mn, Zn, and Cu mineral contents are shown in Figure 5, 6, and Figure 7. Each AP, BF, and AB systems have different dynamics of mineral retention in fish, vegetables, and water. Also, there has been an accumulation or reduction in the retention dynamics of the minerals.

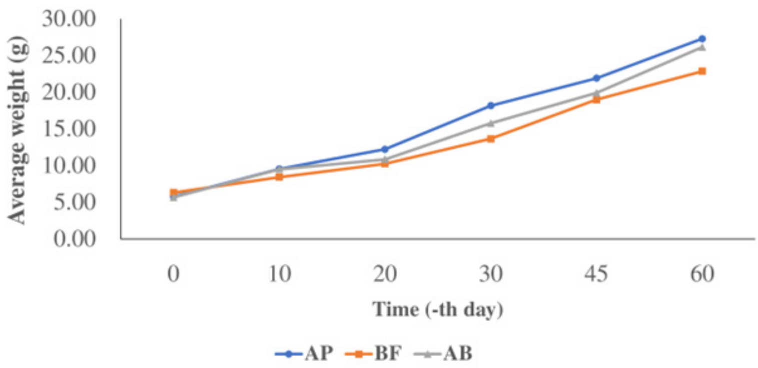

Figure 4. Nile tilapia weight growth rate for 60 days.
Note: AP = Aquaponics; BF = Bioflocs; AB = Aquabioponics.

Table 3. Production performance of Nile tilapia on each rearing system.

Parameter (unit)	System		
	Aquaponics	Bioflocs	Aquabioponics
Survival rate (%)	85.5 ± 8.72[a]	80.5 ± 9.66[a]	84.67 ± 12.83[a]
Specific length growth rate (%/day)	0.90 ± 0.05[a]	0.72 ± 0.02[b]	0.83 ± 0.03[a]
Specific weight growth rate (%/day)	2.62 ± 0.08[a]	2.16 ± 0.04[b]	2.58 ± 0.14[a]
Harvest biomass (kg)	4.28 ± 0.19[a]	3.34 ± 0.41[b]	3.55 ± 0.47[ab]
Total feed intake (kg)	3.69 ± 0.31[a]	2.59 ± 0.20[b]	2.93 ± 0.19[b]
Feed conversion ratio	1.17 ± 0.02[a]	1.06 ± 0.11[a]	1.19 ± 0.01[a]
System productivity (g/L)	4.55 ± 0.48[a]	4.08 ± 0.52[a]	3.77 ± 0.25[a]
Total water requirement (L)	694.67 ± 22.14[b]	603.33 ± 7.64[a]	696.67 ± 6.81[b]

*) Numbers in the same line followed by different letters show a significant difference at 5% confidence level (Duncan's test).

Table 4. Vegetable production performance in AP and AB systems.

Parameter (unit)	System		P value
	Aquaponics	Aquabioponics	
Average hervested vegetables at D0-D30 (g)	12.4 ± 4.15[a]	7.81 ± 1.31[b]	< 0.05
Harvested vegetable biomass at D0-D30 (g)	272.37 ± 55.64[a]	189.04 ± 51.34[b]	< 0.05
Average hervested vegetables at D31-D60 (g)	6.25 ± 2.01[a]	2.46 ± 0.40[b]	< 0.05
Harvested vegetable biomass at D31-D60 (g)	146.61 ± 38.1[a]	63.1 ± 9.14[b]	< 0.05
Harvested vegetable biomass accumulation (g)	418.98 ± 76.87[a]	252.14 ± 44.32[b]	< 0.05

*) Numbers in the same line followed by different letters show a significant difference at 5% confidence level (F-Test Two-Sample for Variances).

Table 5. Mineral retention by fish, vegetable, and water in AP, BF, and AB treatments.

Mineral	Parameter (unit)	Aquaponics	Bioflocs	Aquabioponics	P value
P	Fish retention (%)	3.97 ± 0.07^{a}	3.67 ± 0.43^{ab}	3.39 ± 0.06^{b}	0.042
	Vegetable retention (%)	5.19 ± 0.81^{a}	-	3.58 ± 0.78^{b}	< 0.05
	Water retention (%)	11.9 ± 5.66^{ab}	23.53 ± 8.6^{a}	1.72 ± 1.22^{b}	0.012
K	Fish retention (%)	1.63 ± 0.06^{ab}	1.77 ± 0.18^{a}	1.42 ± 0.02^{b}	0.021
	Vegetable retention (%)	17.26 ± 2.1^{a}	-	11.34 ± 1.37^{b}	< 0.05
	Water retention (%)	30.75 ± 6.43^{a}	35.85 ± 3.4^{a}	33.71 ± 9^{a}	0.663
Ca	Fish retention (%)	2.79 ± 0.19^{b}	3.77 ± 0.34^{a}	2,94 ± 0.09^{b}	0.005
	Vegetable retention (%)	11.79 ± 1.14^{a}	-	7.33 ± 1.42^{b}	< 0.05
	Water retention (%)	-6.24 ± 2.09^{b}	7.97 ± 4.14^{a}	-6.31 ± 5.33^{b}	0.008
Mg	Fish retention (%)	3.05 ± 0.3^{a}	2.8 ± 0.25^{a}	2.9 ± 0.15^{a}	0.5
	Vegetable retention (%)	3.64 ± 0.85^{a}	-	1.34 ± 0.1^{b}	< 0.05
	Water retention (%)	-6.13 ± 1.42^{a}	-1.59 ± 1.02^{b}	-1.32 ± 0.64^{b}	0.002
Fe	Fish retention (%)	1 ± 0.03^{c}	1.78 ± 0.15^{a}	1.24 ± 0.02^{b}	0.001
	Vegetable retention (%)	21.59 ± 2.71^{a}	-	14.79 ± 1.75^{b}	< 0.05
	Water retention (%)	3.58 ± 0.59^{c}	21.64 ± 2.82^{a}	8.15 ± 2.4^{b}	0.001
Mn	Fish retention (%)	-0.4 ± 0.01^{b}	-0.44 ± 0.05^{b}	-0.61 ± 0.1^{a}	0.014
	Vegetable retention (%)	22.17 ± 3.66^{a}	-	14.9 ± 3.89^{b}	< 0.05
	Water retention (%)	-21.77 ± 4.88^{c}	4.37 ± 0.77^{a}	-12.75 ± 4.37^{b}	0.001
Zn	Fish retention (%)	-2.15 ± 0.19^{b}	-2.06 ± 0.34^{b}	-2.71 ± 0.19^{a}	0.038
	Vegetable retention (%)	12.54 ± 1.27^{a}	-	7.53 ± 1.61^{b}	< 0.05
	Water retention (%)	-12.34 ± 5.97^{b}	3.4 ± 0.23^{a}	-1.97 ± 1.41^{a}	0.004
Cu	Fish retention (%)	-1.92 ± 0.17^{a}	-1.83 ± 0.32^{a}	-2.11 ± 0.12^{a}	0.334
	Vegetable retention (%)	4.46 ± 0.39^{a}	-	2.96 ± 0.55^{b}	< 0.05
	Water retention (%)	-2.01 ± 1.31^{ab}	3.55 ± 0.46^{a}	-7.75 ± 5.08^{b}	0.011

*) Numbers in the same line followed by different letters show a significant difference at 5% confidence level (Duncan's test for mineral retention of fish and vegetable, F-Test Two-Sample for Variances for mineral retention of vegetables). Note: P= Phosphate; K= Potassium; Ca= Calcium; Mg= Magnesium; Fe= Iron; Mn= Manganese; Zn= Zinc; Cu= Copper.

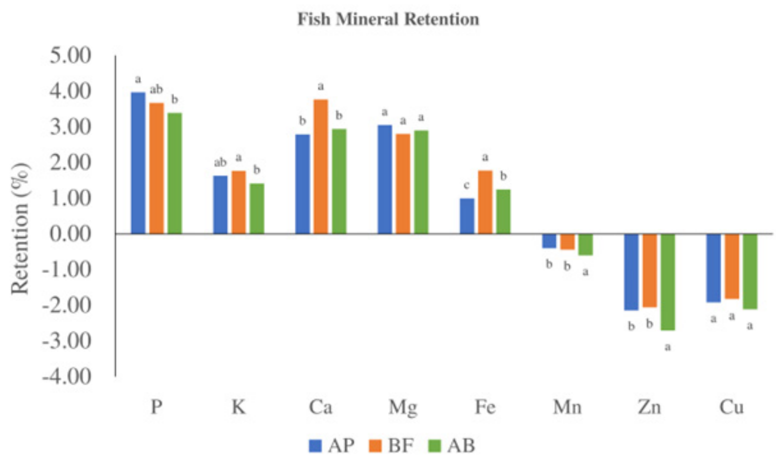

Figure 5. Fish mineral retention in each treatment, based on the mineral content analyses.
Note: AP= Aquaponics; BF= Bioflocs; AB= Aquabioponics; P= Phosphate; K= Potassium; Ca= Calcium; Mg= Magnesium; Fe= Iron; Mn= Manganese; Zn= Zinc; Cu= Copper.

Discussions

The water temperature values of the three treatments was measured at 23.8–27.3°C, as the optimum range for tilapia rearing. According to Perschbacher and Stickney (2017), the optimum temperature range for tilapia culture is 20–30°C. The water pH value from the three treatments was at 6.61–8.52, as also the optimum range for tilapia rearing. According to Cavalcante *et al*. (2014), the optimum pH value for tilapia culture is 6–9. The water alkalinity values of the three treatments obtained a range of 11.54–108.46 mg/L and were still sufficient for tilapia rearing.

Wongkiew *et al*. (2017) recommend an alkalinity range of 100–150 mg/L for an aquaponic system to buffer the pH value properly. The dissolved oxygen in water (DO) of the three treatments showed no different value range, whereas the highest DO value was 5.8 mg/L at initial rearing period, then decreased until reaching the lowest value at 1.13 mg/L on the 60-th day of rearing period. Decreased DO value was occurred due to an increased fish biomass growth during the rearing period, so that the use of oxygen by fish and microbial activity became higher. The low DO value in this study was caused by high stocking density of tilapia at 4 fish/10L. Nonetheless, tilapia have the ability to tolerate low dissolved oxygen levels for limited period.

Tilapia can survive up to 0.3 mg/L DO level due to the ability to take up oxygen from the air on the water surface (Perschbacher and Stickney, 2017). Floc volume was only formed in the biofloc treatment at 8–40 mL/L for 60 days. In the aquaponic and aquabioponic treatments, no flocs were formed in the water, as the floc was

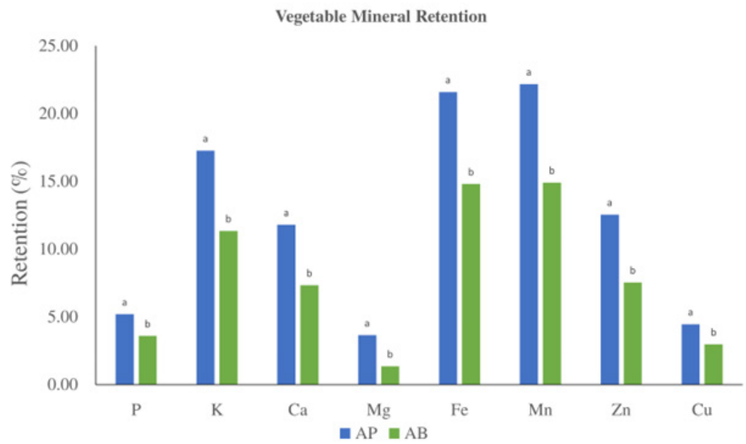

Figure 6. Vegetable mineral retention in each treatment, based on the mineral content analyses.
Note: AP= Aquaponics; BF= Bioflocs; AB= Aquabioponics; P= Phosphate; K= Potassium; Ca= Calcium; Mg= Magnesium; Fe= Iron; Mn= Manganese; Zn= Zinc; Cu= Copper.

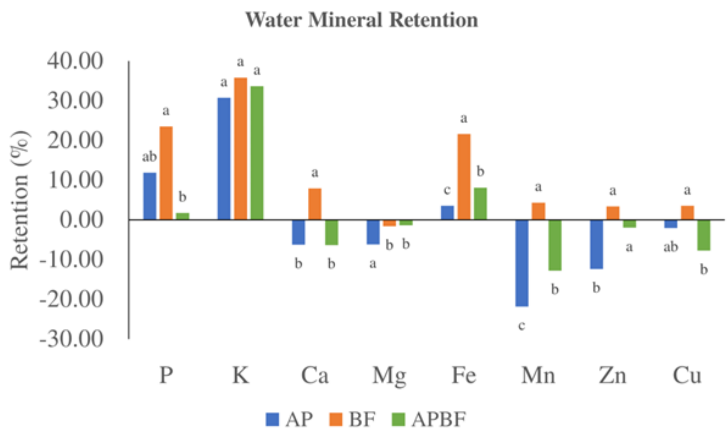

Figure 7. Water mineral retention in each treatment, based on the mineral content analyses.
Note: AP= Aquaponics; BF= Bioflocs; AB= Aquabioponics; P= Phosphate; K= Potassium; Ca= Calcium; Mg= Magnesium; Fe= Iron; Mn= Manganese; Zn= Zinc; Cu= Copper.

trapped in the kaldness filter media container and stuck to the roots of the bok-choy. High stocking density of tilapia at 4 fish/10L was applied in this study. Other studies regarding the production performance of tilapia in the biofloc system applied stocking densities at 1-3 fish/10L (Aboseif *et al*., 2022; Haridas *et al*., 2017; Laice *et al*., 2021; Liu *et al*., 2018).

The application of high fish stocking densities can result in a high loading of ammonia into the rearing media. Boyd and Tucker (1998) explained that 0.03 kg of ammonia is excreted by fish from every consumption of 1 kg of feed, containing 25-40% protein. Although the stocking density applied in this study was high, the results showed that the ammonia content during fish rearing in the three treatment systems was still tolerable for tilapia, namely at 0.01–1.3 mg/L. Ortiz *et al*. (2022) showed that the sublethal ammonia level for tilapia was 2.476 mg/L. Based on the study, the BF treatment showed the best measurement results for ammonia levels due to below 0.05 mg/L. However, increased ammonia levels up to 1.3 mg/L and 1.27 mg/L were found in the AP and AB treatments, respectively. The nitrite concentration values obtained from each treatment was also tolerated by tilapia, as the highest untolerable level was 3.44 mg/L.

Yanbo *et al*. (2006) stated that the lethal concentration (LC_{50}) value of nitrite in tilapia was 28.18 mg/L. The value of the nitrate concentration obtained from each treatment was 0.58–4.27 mg/L, as a good value for tilapia rearing. According to Gullian-Klanian and Arámburu-Adame (2013), nitrate is relatively harmless to tilapia. Monsees *et al*. (2016) recommended that nitrate concentrations should not exceed 500 mg/L as optimal conditions for fish health and growth in juvenile tilapia rearing. The survival rate of tilapia between treatments in the study did not show a significant difference ($p>0.05$), namely at 80.5 ± 9.66 to 85.5 ± 8.72.

The tilapia production performance that showed significant differences ($p<0.05$) was occurred in specific length growth rate, specific weight growth rate, harvest biomass, and total feed intake. Meanwhile, the feed conversion ratio and system productivity did not show a significant difference ($p>0.05$). The specific length and weight growth rates between the aquaponic and aquabioponic treatments were not significantly different ($p>0.05$), but both were significantly different ($p<0.05$) with the biofloc treatment. The highest specific length and weight growth rates in were obtained from the aquaponic treatment, while the lowest was occurred in the biofloc treatment. The harvest biomass of the aquaponic treatment was significantly different ($p<0.05$) from the biofloc treatment, while the aquaponic treatment had no significant difference ($p>0.05$) between the aquaponic and biofloc treatments.

The highest harvest biomass was obtained from the aquaponic treatment, while the lowest was obtained from the biofloc treatment. The total feed intake in the aquaponic treatment was significantly different ($p<0.05$) from both biofloc and aquabioponic treatments, while the aquaponic treatment had no significant different ($p>0.05$) with the biofloc treatment. The highest feed intake was obtained from the aquaponic treatment, while the lowest was obtained from the biofloc treatment. Based on the study results, the best tilapia production performance is in the aquabioponic system, while the lowest is in the biofloc system. This condition was occurred as aquabioponic production has no significant difference with aquaponics, but aquabioponics provide less feed application than aquaponics.

Based on the measurement results of the water physiochemical parameters which are more similar between each treatment, it is likely that the production performance gain is greatly influenced by the total feed intake. Although the ammonia value in the biofloc treatment showed the best results, the production performance of the biofloc treatment obtained the lowest results. Thus, the ammonia value does not affect the acquisition of fish production performance in this study. Based on this condition, it is possible that the water physiochemical parameters that affect the low production performance in biofloc system are the presence of floc in the water.

The floc in the biofloc system is consumed by the tilapia, reducing the fish consumption on feed, yet in this study, a lower fish production performance was found, compared to the aquaponic system. This may occur as fish were full by feeding on floc, thereby reducing the feed response, but the nutrient content in floc was lower than in feed, resulting a lower production performance. In another study conducted by Ekasari *et al*. (2014), the biofloc produced contained 17.2-27.8% protein and 6-7.5% lipid. The allegation of fish consuming flock can reduce the performance production was also supported by the results of calculating the feed conversion ratio which did not show a significant difference ($p>0.05$) among aquaponic, biofloc and aquabioponic treatments.

This means that tilapia in the aquaponic and aquabioponic systems consume more feed, thus producing a higher fish growth performance than biofloc system, that consumes less feed and causes a lower fish growth performance with the same proportion. Therefore, it does not cause differences in feed conversion ratio value. This is also thought that fish production in aquaponics is not significantly different from aquabioponics, but the use of feed in aquabioponics is significantly less than aquaponics. It may occur that the floc is actually formed and consumed by the fish, but the floc formed is less than in biofloc and does not accumulate in the water column of the tilapia rearing tank. The system productivity values did not show a significant difference ($p>0.05$) between the aquaponics, bioflocs, and aquabioponics, although a significant differences were found in growth parameters.

Although the fish growth in the aquaponic and aquabioponic systems was higher than in the biofloc system, the aquaponic and aquabioponic systems used more water than the biofloc system. More water use in the aquaponic and aquabioponic systems were caused by the higher rate of water evaporation and circulation process from the tilapia rearing tank to the bok-choy planting media, besides the water absorption by the plants, needed for the growth of the vegetables. The production performance of bok-choy in the aquaponic and aquabioponic treatments showed a significant difference ($p<0.05$) in all parameters, as the aquaponic system had better production result than aquabioponics. The production performance value in vegetable was also consistent with the retention value, as there was a significant difference ($p<0.05$) in all mineral retention and a higher yields of minerals in the aquaponic system than aquabioponics.

The vegetable growth in the aquaponic system was strongly influenced by plant roots. Inside the roots, water and dissolved minerals are transported through the xylem for photosynthesis (Resh, 2013). Based on this theory, the lower production performance and mineral retention by vegetables in aquabioponics may be due to certain conditions in the roots of aquaponic vegetables, resulting in poor absorption of water and minerals. In aquabioponics, more sediment is formed from the floc that covers the roots, whereas less sediment is found the roots on the aquaponic system. More clean root in aquaponic impact to a better production performance and mineral retention.

Mineral retention in fish can occur in several ways, i.e by directly digesting suspended particles in the water column as food, ion exchange of dissolved elements across lipophilic membranes (e.g. gills), and adsorption of mineral elements on tissue and membrane surfaces (Edevaldo *et al*., 2016). In closed fish farming systems such as aquaponics, biofloc, and aquabioponics applied in this study, the source of mineral input was feed and tapioca flour, as applied in both biofloc and aquabioponic treatments. Minerals from feed will first be retained by fish, then the undigested minerals in feces will be mineralized by bacteria in a dissolved form in the water, thus can be utilized by vegetable plants. Therefore, this study attempts to observe the flow of mineral utilization by fish (fish retention), vegetables (vegetable retention), and available minerals in water (water retention).

From the study results, the retention dynamics were varied between P, K, Ca, Mg, Fe, Mn, Zn, and Cu in each treatment. The mineral retention results indicate mineral accumulation with an increased final mineral content as positive retention value and mineral reduction with a decreased final mineral content as negative retention value. The water mineral retention needs to be a major concern due to a reduction of certain minerals in the water, which means that the system may need to gain input from additional mineral sources apart from feed. Mineral retention by fish showed the accumulation of P, K, Ca, Mg, and Fe minerals, but reduction occurred in Mn, Zn, and Cu minerals.

The mineral retention by fish among treatments showed a significant difference ($p<0.05$) in P, K, Ca, Fe, Mn, and Zn minerals, while the retention of Mg and Cu minerals did not show a significant difference ($p>0.05$). The highest mineral accumulation value and the lowest reduction tended to occur in the BF treatment (K, Ca, and Fe minerals), but showing a lower value than the AP and AB treatments. Mineral retention by plants showed that the AP treatment obtained a higher and significantly different accumulation value ($p<0.05$) than the AB treatment for P, K, Ca, Mg, Fe, Mn, Zn, and Cu minerals. This was also consistent with the performance value of vegetable production in the AP treatment.

Mineral retention by water showed significantly different values ($p<0.05$) among treatments for all minerals, except K mineral. The P, K, and Fe minerals accumulated in the three treatments, while Mg mineral was reduced in the three treatments. The Ca, Mn, Zn, and Cu minerals were reduced in AP and AB treatment, but accumulated in BF treatment. Based on the mineral retention by water, Ca, Mg, Mn, Zn, and Cu minerals may become essential minerals in both aquaponic and aquabioponic systems, while Mg becomes the essential mineral in the biofloc system.

CONCLUSION

The aquabioponic system produces the best tilapia production performance, as fish consume the same amount of feed as biofloc treatment but produce higher growth rates and biomass yields than biofloc. Biofloc can be combined with aquaponics to increase fish growth, but it needs to be optimized to produce better vegetable production. The Ca, Mg, Mn, Zn, and Cu minerals are thought to be essential minerals in aquaponic and aquabioponic systems, while essential mineral in the biofloc system is thought to be Mg.

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