Pertanika J. Trop. Agric. Sci. 46 (4): 1259 - 1274 (2023)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Effects of Nutritional and Culture Medium-based Approaches for Aquaponics System with Bio-floc Technology on Pak Choi and Catfish Growth Rates

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ABSTRACT

Aquaponics with bio-floc can potentially offer sustainable food production with zero waste as it allows farming plants and fish simultaneously, whereby the former use fish waste as their nutrient sources, while the latter receives cleaner water from the plants in a closed-loop system. In the aquaponics system, additional nutrients are usually added to support optimal plant growth, but it is suggested that the amount of such chemical nutrients should be controlled to prevent any harm to the fish. Furthermore, the plant and fish growth rates are influenced by the nutrients and the culture media used. This study aims to examine the effect of nutrition (full-nutrient and half-nutrient treatments) and different types of culture mediums (rockwool, rockwool-perlite, and rockwool-husk) on the growth rates of pak choi (*Brassica rapa*) and catfish (*Clarias gariepinus*) using split-plot design. Findings show that the half-nutrient treatment yielded a 17.12% higher plant growth rate and 23.87% heavier catfish weight than the full-nutrient treatment, but these treatments did not affect the fish survival rate. It was also observed that using different culture mediums did not result in any significant difference.

Keywords: Aquaponics, *Brassica rapa*, *Clarias gariepinus*, culture medium, nutrition treatment

INTRODUCTION

As the growing population has spurred more demands for food supply and yet the land use for agriculture has become increasingly limited, food production efficiency is

ARTICLE INFO

Article history:
Received: 25 April 2023
Accepted: 07 July 2023
Published: 31 October 2023

DOI: https://doi.org/10.47836/pjtas.46.4.12

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ISSN: 1511-3701
e-ISSN: 2231-8542

essential to meeting the food demand. At the same time, the food consumption trend has changed toward fresh and healthy commodities, increasing fish and vegetable consumption worldwide (Kearney, 2010). Catering for such demands, aquaponics can be considered one of the potential solutions as it can produce fresh fish and plants in an integrated system. Compared to regular farming or aquaculture systems, aquaponics has the advantage of being able to control and manage the wastewater produced to reduce the environmental impact. Aquaponics can also be operated without vast agricultural land (da Rocha et al., 2017) and easily adopted by home-scale producers and local fish farmers in urban settings.

Aquaponics is a cultivation system that combines aquaculture with hydroponic techniques, wherein the water from the fish rearing tank is flowed to the plants and is returned to the fish farming system in a closed-loop system. The recirculation of water in aquaponics is a filter for any fish waste and decomposed food residue (Harmon, 2005). The water from the fish culture tank will be a source of nutrition for the plants, while the plants will act as a biofilter that can clean the water flowing back to the tank (Zhang et al., 2020). As the main benefit, the aquaponics system does not require commercial fertilizer to grow plants (Prayogo et al., 2021), making it more environmentally friendly. The aquaponics can further be augmented with a bio-floc system to support the nutrient circulation process, where a consortium of microorganisms processes the organic waste into bio-floc, which can be used as additional feed for fish with the rest channeled to plants. The bio-floc technology in the aquaponics system is also economical since it helps improve water quality under a zero water exchange system (Ahmad et al., 2017; Pinho et al., 2022).

Given its popularity, studies on aquaponics have been abundant, but the research focusing on the balanced needs of plants and fish, which are generally contradictory, has not been explored much because the types of commodities cultured—in this case, fish and plants usually have to be compatible to be farmed together. For aquaculture commodities, catfish (*Clarias gariepinus*) is a suitable fish species owing to their additional breathing apparatus called arborescent (Abd-Elmaksoud et al., 2008; Belão et al., 2015) and their tolerance to total dissolved solids (TDS) of up to 1,000 ppm in the water (Popoola et al., 2021), whereas for hydroponic farming, pak choi (*Brassica rapa*) is a commonly cultivated plant because of its relatively short cultivation period, simple farming and high dietary value (Echer et al., 2015; Ewert, 2004). Normally, pak choi can grow well at a nutrition concentration of 1,000–1,400 ppm, with optimum growth at 1,200 ppm and an ideal pH of 5.0-8.0 (Akasiska et al., 2014).

Nevertheless, aquaponics has an issue: the conflicting needs between plant growth and fish growth. Even though some nutrients are already available from the residual aquaculture waste, which contains organic nitrogen (N), phosphorus (P), and carbon (C) (Saba & Steinberg, 2012), the plants still need additional nutrients that are not found in fish pellets. However, adding nutrients creates a dilemma between high nutritional requirements for plants and clean water quality (low nutrition) for fish. Adding more nutrients, however, may create a dilemma between high nutritional requirements for plants and clean water quality (low nutrition) for fish. While plants usually require high nutrient content and can benefit from the high TDS value in the circulating water in the aquaponics systems (Afolabi, 2020; Nozzi et al., 2018), large amounts of TDS are directly harmful to fish and indirectly decrease pH and oxygen solubility in the water. Therefore, the nutrients to be added should be restricted to the elements that plants need that exist in lower-than-desirable quantities in fish feed or waste, namely calcium (Ca), potassium (K), and iron (Fe) (Bittsanszky et al., 2016; Kasozi et al., 2019; Sastro, 2015).

The culture medium is another factor that may affect plant growth in aquaponics systems (Oladimeji et al., 2020). With its primary function to hold and provide plant roots with adequate moisture and oxygen and to support their weight, the culture medium is expected to be highly water absorbent, have good aeration, and be free of toxins. One of the most common mediums used in hydroponics is rockwool, which originates from heated basalt spun into a wool-like block. Rockwool is popular for its high water-holding capacity, good aeration, and sturdiness (Ingram et al., 2003). However, its solidity and sturdiness may hinder root movement, limiting the aeration inside the medium (Resh, 2015). The rockwool can be mixed with another medium, like perlite volcanic glass (alumina-silicate) that has been heated until it expands to increase the aeration. Perlite is light and resistant to bacteria degradation, and although it has a lower water-holding capacity than rockwool, perlite is usually used with another medium to provide better aeration in the medium (Ingram et al., 2003). Another medium commonly used is burnt rice husk. Not only is this medium able to hold water and aerate the medium well, but it can also absorb and neutralize toxic minerals in the water. Moreover, burnt rice husk is not easily decomposed by bacteria and can replace other growing media (Kaudal et al., 2016).

In conventional aquaculture systems, non-consumed fish feed and other waste are regularly discarded through water replacement or filtration because they are noxious to fish. However, in an aquaponics system combined with bio-floc technology, the waste is useful as additional fish feed after being processed by bacteria and other microorganisms. Floc-forming bacteria manipulate the carbon-nitrogen (C/N) ratio to convert the toxic nitrogenous waste into beneficial bacteria, forming microbial protein that can be used as an additional source of food for fish (Pattilo, 2017). Previous studies have shown that bio-floc technology can reduce fish feed by up to 20% (Ogello et al., 2014), potentially increasing the financial feasibility of aquaponics production. In addition, the floc-forming bacteria can help improve fish health and water quality, which is critical in the circulation system (Ahmad et al., 2017; Gallardo-Collí et al., 2019). Given these advantages, bio-floc allows aquaponics to be a sustainable zero-waste food production system.

The present research aims to examine the growth rates of pak choi and catfish cultured through nutritional and culture medium-based approaches in the aquaponics system integrated with bio-floc technology. However, as the bio-floc implementation was still in the preliminary stage, the water quality parameters in the bio-floc application, such as the ammonia, nitrite, and nitrate levels, were beyond the scope of this study. This research will likely be the first to examine the potential use of a commercial nutrient solution in an aquaponics system with bio-floc to improve plant production while mitigating its adverse effect on fish health. The findings can eventually help enhance the productivity and profitability of aquaponics systems by indicating the optimal amount of nutrients (Ca, K, and Fe) that can be added to support plant growth without harming the fish.

MATERIALS AND METHODS

This research was conducted for eight months in the Aquaculture Laboratory, Atma Jaya Catholic University of Indonesia campus in Tangerang, West Java (6°19’S, 106°39’E, and altitude 44 m). The research began with an initial study on the design of the aquaponics system, which included water circulation from and to the hydroponic plots, a sunlight intensity system, and a feeding system. The primary process consisted of aquaponics installation, nutrient, and sample preparation, weekly monitoring and measurement, and final measurement and statistical analysis.

Aquaponics Installation and Experimental Design

A split-plot design was developed using six aquaponics sets, each containing a 1 m^3-square tank and ten hydroponic pipes with 90 holes, resulting in 540 holes available for growing plants. The tank was filled with fresh water, and bio-floc was grown by adding probiotic bacteria (EM4, Songgolangit Persada, Indonesia) for two weeks. When bio-floc was formed, 850 catfishes (*Clarias gariepinus*) of 1-month-old (9–11 cm) with an average weight between 4 to 5 g were put in each tank. The growing bio-floc was characterized by a change in the water color to greenish and the formation of small blackish-green clumps suspended in the water. The main plot was divided based on nutrient concentration (full-nutrient and half-nutrient), while the subplot was based on the culture medium (rockwool, rockwool-perlite, and rockwool-husk). Three aquaponics sets were used for the full-nutrient experiment and the rest for the half-nutrient one. Figure 1 shows the installation of the aquaponics system used in this study and the layout of each aquaponics set. Each set was equipped with a submersible impeller pump to circulate the water at a rate of 500 ± 5 L/hr. Intensive turbulent mixing generated by the air pump installed inside the tank and the returning waterfall from the hydroponic pipes would provide aeration for the aquaculture system.

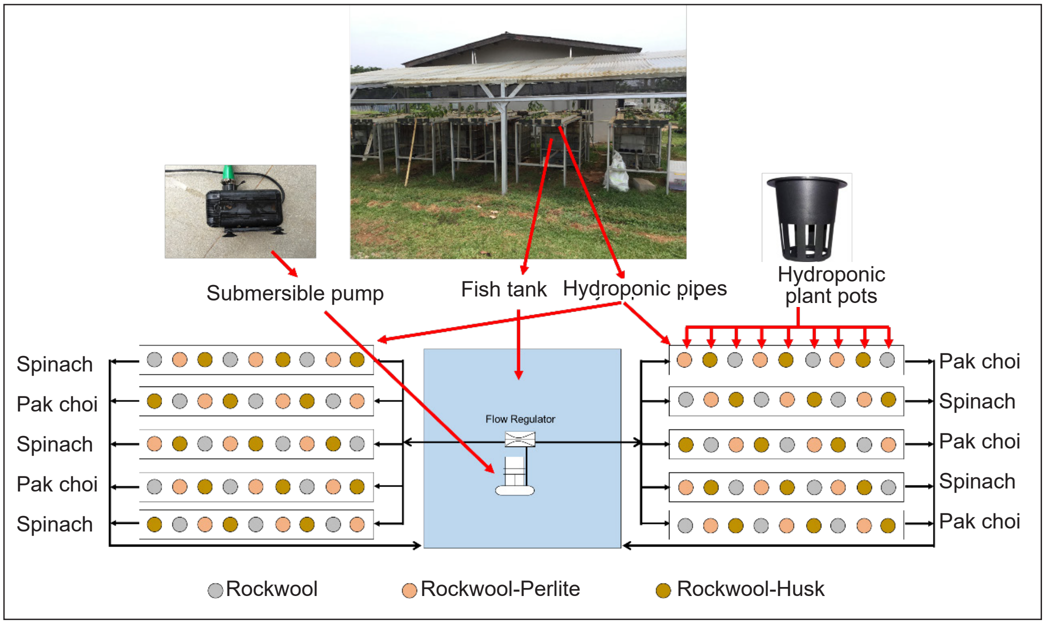


Figure 1. Aquaponics installation and layout

Lastly, nets were used to reduce excessive light intensity and protect the aquaponics from external conditions such as wind and rainfall. Initially, two types of plants were cultivated in the aquaponics systems: pak choi (*Brassica rapa*) and spinach (*Spinacia oleracea*). However, most spinach seeds failed to germinate; hence, the study would focus more on the pak choi.

Nutrient and Sample Preparation

The additional nutrition used for the plant was AB Mix nutrient (Agrifarm, Indonesia), which is well known in hydroponics farming. AB represents the two types of nutrients packaged separately, intended to prevent clumping when put together in the same package. The clumping usually occurs due to a chemical reaction between mineral salts or the crystallization of the nutrients. In detail, nutrient stock A represents macronutrients containing elements such as nitrogen (N) and phosphorus (P), while nutrient stock B represents micronutrients such as iron (Fe), copper (Cu), and chlorine (Cl). The composition of nutrients A and B for 1,000 L of water is shown in Table 1. The full-nutrient treatment was controlled using AB Mix at a final concentration of 1,200 ppm, while the

Table 1
The composition of AB Mix

Composition	Value (g)
Nutrient A	
Ammonium nitrate	616
Potassium nitrate	1176
Fe-EDTA	38
Nutrient B	
Manganese sulphate	8
Magnesium sulphate	790
Zinc sulphate	1.5
Copper sulphate	0.4
Potassium dihydrophosphate	335
Ammonium heptamolybdate	0.1
Boric acid	4

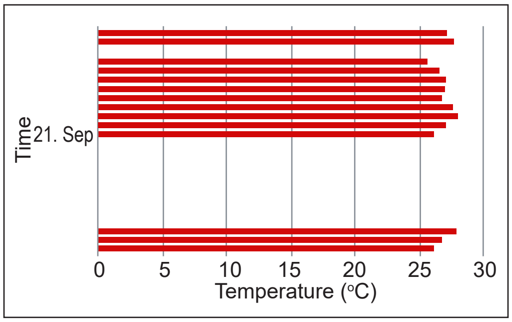
half-nutrient treatment was controlled at a final concentration of 600 ppm. For the half-nutrient treatment, 3.54 g of iron (II) sulfate ($FeSO_4$), 471.25 g of calcium carbonate ($CaCO_3$), and 462.55 g of potassium hydroxide (KOH) were also added.

Pak choi seeds were soaked and planted in rockwool measuring 3 × 3 × 3 cm^3, which were then sprayed with water using a sprayer. After ten days, the plants with four leaves were ready to be transferred to three different aquaponics pots, which contained only rockwool, rockwool-perlite, and rockwool-husk (according to medium treatments), respectively. Each was placed on an aquaponics plot with a nutrient flow technique (NFT) system.

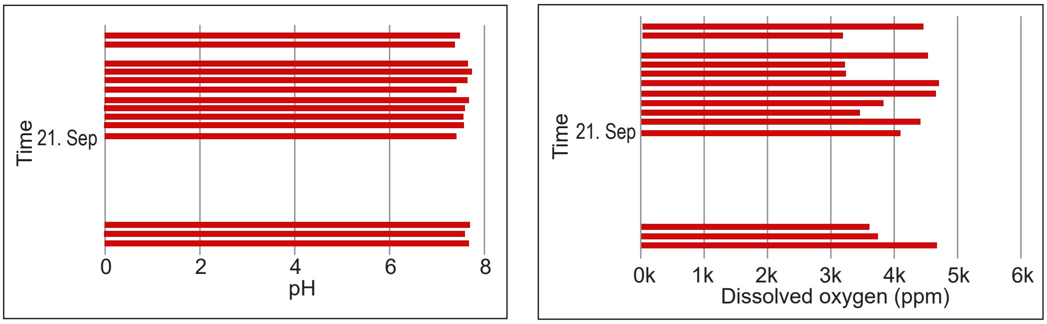
Monitoring and Weekly Measurement

An Arduino-based control system was designed to monitor and maintain the water temperature, pH level, and dissolved oxygen (DO) in the aquaculture tanks, ensuring that the aquaponics ran optimally. The pH level in the tank was maintained at around 7.5, which is highly recommended for the optimal growth and development of catfish. At the same time, the dissolved oxygen was always preserved at a level above 3,000 ppm. As shown in Figure 2, the temperature, pH, and DO measurement data obtained from the Arduino sensor was hosted on the open-source analytical platform ThingSpeak Internet-of-Things.

Maintenance was also conducted daily to control the amount of TDS, as illustrated in Table 2. In the full-nutrient treatment, an AB Mix concentration of 600 ppm was initially added in week 1 and gradually increased to its final concentration of 1,200 ppm in week 4. Meanwhile, the AB Mix concentration in the half-nutrient treatment started at 300 ppm and rose to 600 ppm in the third and fourth week. Removal of any excess accumulated floc deposits in the fish tanks was conducted



(a)



(b)

(c)

Figure 2. (a) Temperature; (b) pH; and (c) and dissolved oxygen measurement data

Table 2

The total dissolved solids maintenance provisions

Nutrition treatment	Initial	1st week	2nd week	3rd week	4th week
Full (ppm)	600	800	1,000	1,200	1,200
Half (ppm)	300	400	500	600	600

weekly to prevent clogging in the hydroponic pipes. In addition, visual inspections of the hydroponics sections were carried out twice weekly to ensure no solids were built on the plant's roots.

Final Measurement and Statistical Analysis

Final measurements were conducted during the fourth week. Two plants were taken from each culture medium treatment for final measurements for each nutrient treatment. The final measurement examined the stem weight, height, chlorophyll *a*, and chlorophyll *b*. The stem height was measured from the medium's surface to the plants' apical shoots. In contrast, the chlorophyll content was measured by following Harborne's (1998) method. A total of 0.1 g of leaves were crushed using a mortar until they became fine powder, after which 10 ml of 80% acetone (Sigma-Aldrich, Germany) was added. They were then centrifuged for 15 min at 1,593 × *g* and filtered using Whatman filter paper type 41. The chlorophyll content was measured using a spectrophotometer at 646 nm and 663 nm, with its levels determined using the following Equations:

$$\text{Chlorophyll } a = (12.21\ _{\lambda 663} - 2.81\ \lambda_{646})\ \text{mg/L} \qquad [1]$$

$$\text{Chlorophyll } b = (20.13\ _{\lambda 646} - 5.03\ \lambda_{663})\ \text{mg/L} \qquad [2]$$

The growth rates of pak choi and catfish were measured for 4 and 9 weeks, respectively, following their harvest cycle. The survival rate of the catfish was also measured at the end of the production cycle (week 9). Statistical Product and Service Solutions (SPSS) was used to determine the effect of different culture mediums and nutritional treatments on the growth rate of pak choi. The analysis used the analysis of variance test, where in case the analysis of the variance test yielded a significant difference (p <0.05), further analysis was conducted using the post-hoc Tukey's test. The number of leaves was analyzed using a non-parametric test (Kruskal-Wallis' test).

RESULTS

In the initial research stage, three main problems were encountered and solved: bio-floc accumulation in the hydroponic system that blocked the circulation, excessive sunlight that caused the plant to dry out, and nutrient deficiency. First, the water circulation in the hydroponic tank was easily clogged up by the bio-floc, blocking the circulation and causing the water to overflow. To address this issue, an additional water channel was created to return the overflow to the tank. Secondly, the excessive sunlight intensity was reduced by installing the net (60% shade) on the roof and around the wall. The third problem, where the plants showed symptoms of malnutrition in the aquaponics system, as shown in Figure 3, was solved through the nutrient treatment conducted during the main experiment.

The experimental results showed that the half-nutrient treatment produced significantly higher plant height, number of leaves, weight growth, stem weight, stem height, chlorophyll *a*, and chlorophyll *b*, compared to the full nutrient ($p<0.05$), especially during the last week as summarized in Table 3. The chlorophyll *a* and b concentrations were obtained from Equations 1 and 2.

Figure 3. Malnutrition pak choi

The pak choi growth rates, as typified by the number of leaves, height, and weight, initially showed no difference in both treatments during the first week. In the second week, the full-nutrient treatment showed better results than the half-nutrient treatment regarding the number of leaves and height. However, as of the third week, the pak choi growth rate under the half-nutrient treatment was better on every measured variable (number of leaves, height, and weight growth) than the full-nutrient treatment (Figure 4). The error bars represent the standard errors from 36 random samples.

Regarding the culture mediums, no significant difference in the growth rates of pak choi cultivated in rockwool, rockwool-perlite, and rockwool-husk medium was observed on all measured variables (plant height, number of leaves, weight growth, stem weight, stem height, chlorophyll *a*, and chlorophyll *b*), as shown in Table 4.

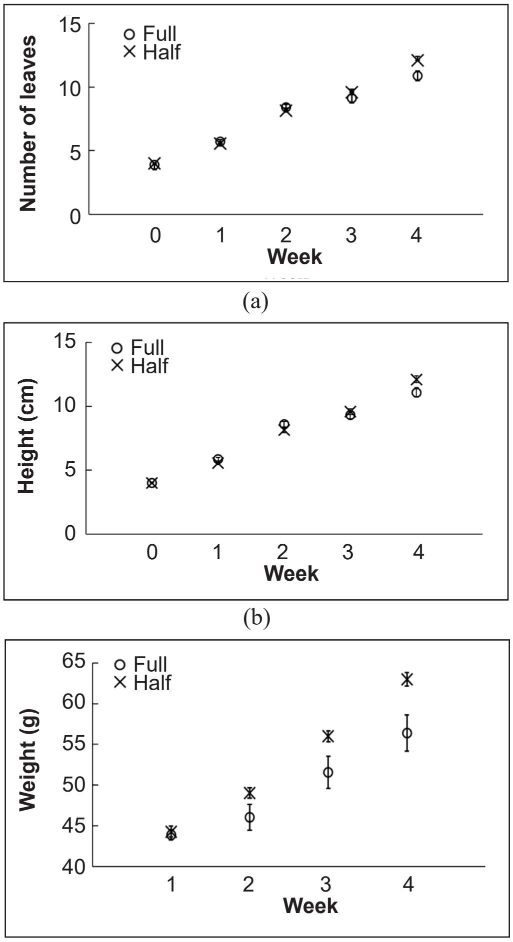
The number of leaves and height from week 0 to week four did not significantly

Table 3

Pak choi growth rate in different nutrient treatment

	Treatment	
	Half-nutrient	Full-nutrient
Height (cm)	14.375 ± 0.221^a	13.177 ± 0.458^b
Total number of leaves	11.917 ± 0.2754^a	11.086 ± 0.483^b
Wet weight (g)	63.167 ± 0.829^a	56.444 ± 2.171^b
Stem weight (g)	22.667 ± 1.278^a	15.444 ± 0.978^b
Stem height (cm)	1.811 ± 0.116^a	1.383 ± 0.108^b
Chlorophyll *a* (µg/ml)	14.281 ± 1.223^a	11.842 ± 1.012^b
Chlorophyll *b* (µg/ml)	4.455 ± 0.386^a	3.524 ± 0.303^b

Note. Different subscripts mean that there is a statistically significant difference



(a)

(b)

(c)

Figure 4. Comparisons of: (a) number of leaves; (b) height; and (c) weight of pak choi for full and half-nutrient treatments

differ in all treatments (Figures 5a and 5b). However, the weight growth of pak choi on rockwool was slightly better compared to that on other culture mediums (Figure 5c), especially during the last week, though the difference was not significant ($p>0.05$).

Regarding the catfish growth rate, the average weight under the full-nutrient treatment was lower, though not significantly ($p>0.05$), than that under the half-nutrient treatment starting from the first week of the experiment, as shown in Figure 6. The data points represent the average weight of sixty randomly selected catfishes from three different tanks for each treatment, and the error bars represent the standard error. Concerning the total production, 245 kg of marketable catfish (10–15 g per fish) were produced and sold at the end of this study, but approximately 20 kg of fish could not be sold as their size is too big (more than 1 kg per fish).

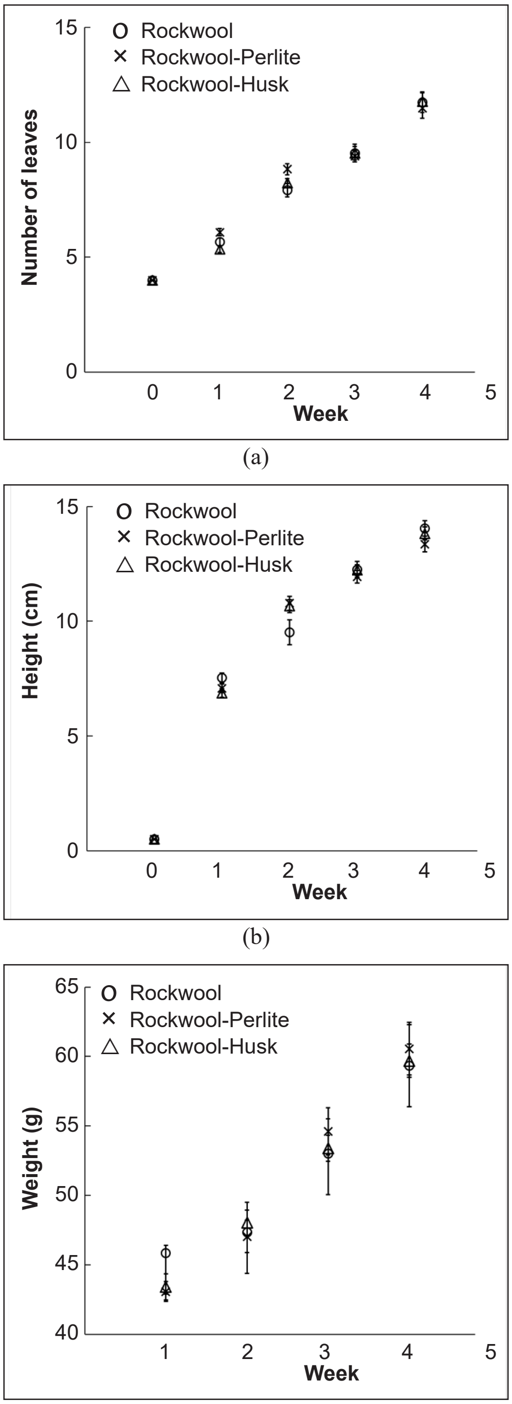
The growing bio-floc in the aquaculture tank was also observed in this study. The concentrations of settleable solids from bio-floc in the water tanks were measured weekly using a 500 ml Imhoff cone after 25

Table 4

Pak choi growth rate in the different medium treatment

	Treatment		
	Rockwool	Rockwool + Perlite	Rockwool + Husk
Height (cm)	13.714 ± 0.68^{a}	13.565 ± 0.343^{a}	13.788 ± 0.282^{a}
Total number of leaves	11.596 ± 0.665^{a}	11.542 ± 0.429^{a}	11.667 ± 0.369^{a}
Wet weight (g)	65.333 ± 2.952^{a}	60.5 ± 1.887^{a}	61.917 ± 1.209^{a}
Stem weight (g)	20.667 ± 1.892^{a}	17.667 ± 1.57^{a}	18.883 ± 1.757^{a}
Stem height (cm)	1.758 ± 0.125^{a}	1.25 ± 0.145^{a}	1.783 ± 0.132^{a}
Chlorophyll a (µg/ml)	13.246 ± 0.602^{a}	12.955 ± 0.522^{a}	12.982 ± 0.59^{a}
Chlorophyll b (µg/ml)	4.061 ± 0.209^{a}	3.934 ± 0.184^{a}	3.974 ± 0.202^{a}

Note. Different subscripts mean that there is a statistically significant difference



(a)

(b)

(c)

Figure 5. Comparisons of: (a) number of leaves; (b) height; and (c) wet weight of pak choi for different culture mediums

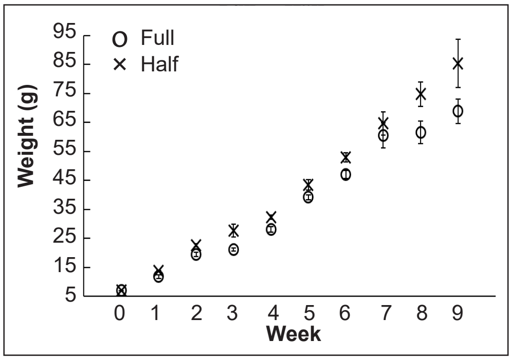


Figure 6. Catfish weight growth

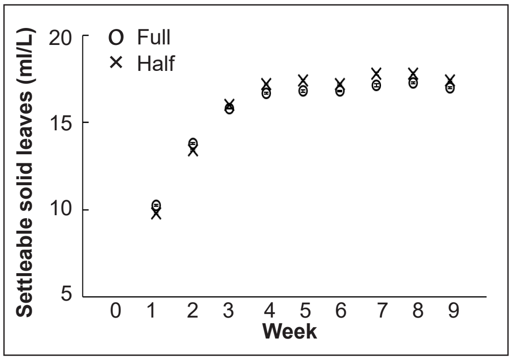


Figure 7. Settleable solids concentration in aquaculture tank

min of sedimentation. It was observed that the settleable solids increased for the first two weeks and started to stabilize around the third week, regardless of the nutrient treatment (Figure 7). It should be noted that further study is required to properly manage the use of bio-floc technology and its impact on aquaponics production.

DISCUSSION

The findings show no interaction between nutrition and culture medium treatments, each independent and not affecting the other. It was also observed that the half-nutrient treatment showed better products of pak choi than the full-nutrient treatment, indicating that the addition of missing elements, namely Fe, Ca, and K, to the half-nutrient treatment made pak choi grow as effectively as it would do in a typical hydroponic system without harming the fish growth. Regarding the function of the missing elements, Fe is vital for plant respiration and chlorophyll formation, Ca stimulates root hair formation, stem hardening, and seed formation, and K helps the formation of protein and carbohydrates (Grusak, 2001). Other nutrients were available in fish feeds, continuously accumulating in the water. This study showed that the half-nutrient treatment was sufficient to promote plant growth, which suggests that aquaponics farmers can increase plant and fish production using a lower dose of a commercial nutrient solution, resulting in a lower operational cost.

As for the fish growth, the half-nutrient treatment yielded better results; the catfish became larger compared to the catfish size in the full-nutrient treatment, confirming the previous study's findings (Sarmento et al., 2020). In the half-nutrient treatment, the catfish were also able to adapt better compared to those in the full-nutrient treatment. Nevertheless, even though the catfish were tolerant to extreme conditions with low DO and high TDS because of their preference towards low-hardness water (Setiadi et al., 2019), it should be noted that the difference in growth rates between the two treatments was statistically not significant. This insignificance might be attributed to the limited number of replications (three times) for the fish growth experiment, necessitating further research with more replications to confirm the difference between the two treatments.

The culture medium treatment did not significantly affect the pak choi's growth, which is likely related to its long roots, which helped the plant obtain water more easily, regardless of the culture medium (Sundar & Chen, 2020). However, during the fourth week, the weight growth rate of the plants in the rockwool medium seemed higher than that in perlite and husk, which was possibly due to rockwool's better ability to store water than that of perlite and husk (Campbell et al., 2021; Ingram et al., 2003).

Similar to the previous research (Priadi et al., 2019), this study has found that the growth rate of pak choi was better in the half-treatment scenario, with the half-nutrient treatment yielding pak choi with better average height (14.38 cm), number of leaves (11.92), and wet weight (63.17 g) compared to the full-nutrient treatment. This slight difference indicates that the additional nutrient in the half-nutrient treatment can sufficiently compensate for the deficiency of Fe, Ca, and K nutrients in conventional aquaponics cultivation. In relation to the previous study by Nozzi et al. (2018) that demonstrates how adding supplements may accelerate plant growth but reduce the plant's nutritional quality, this study has presented the half-nutrient addition as a suitable concession to support the plant growth while maintaining most of its nutritional quality. Not only that, but the proper amount of the nutrient dose also prevented any harm to the fish. Furthermore, this study attests to pak choi's suitability for aquaponic farming because it typically requires minimal supplement addition, tolerates low-medium ppm levels, and does not take too much space, resulting in efficient management and cost. Lastly, the findings confirm the suitability and positive effect of employing a bio-floc system on pak choi cultivation in aquaponics (Fimbres-Acedo et al., 2020).

This study also demonstrates what fish are suitable to farm in aquaponic systems. The water conditions in the aquaponic system are often turbid, resulting in low DO levels. Such an issue is even exacerbated with the addition of bio-floc technology (da Rocha et al., 2017). Therefore, the ideal types of fish to farm in aquaponic systems are those with an extra respiratory system and the ability to tolerate unfavorable environments. Furthermore, aquaponics is generally optimized for food production with high fish stocking density in the tank, meaning that the best fish to raise in aquaponics must be able to live in groups since the space between fish is limited (Setiadi et al., 2019). With all these considered, catfish are ideally suited for aquaponics due to their air-breathing capabilities and hardiness.

Nonetheless, the existing aquaponics system does still have some challenges. Firstly, the aquaponics system operated in this study is laboratory-scale, which may not properly replicate semi-commercial and large-scale commercial aquaponic operations. As commercial aquaponics normally seek a maximum production output (Palm et al., 2018), the aquaponics system in this research might not be financially sustainable since its intended design is not for economic production. Secondly, the application of bio-floc in this study is still in the preliminary stage, where critical water quality parameters in bio-floc technology, such as ammonia, nitrite, and nitrate, were not carefully maintained. Further research is needed to evaluate and optimize the water parameters and operating conditions to help maximize the bio-floc's effectiveness in increasing fish production in aquaponics. In addition, this study discovered that the current aquaponics system with bio-floc was less efficient because large floc deposits were still left at the end of the production cycle, which would likely require some cleansing. In light of the large number of floc deposits, it is therefore recommended that the number of fish and plants be balanced to reduce the excessive floc. Correspondingly, it is also suggested that the culture medium with larger pores be used to avoid clogging caused by the floc deposits since clogging can disrupt the plant's respiration due to the lack of aeration (Goddek et al., 2015). In future research, the leftover flocs should ideally be utilized as bio pellets to feed the fish to help minimize costs since fish food is one of the most significant cost factors during this study. Using bio pellets can then significantly improve the profitability of the aquaponics system.

Despite the current shortcomings, this study has demonstrated the potential of aquaponics as a sustainable food cultivation system that allows the urban population to produce fresh food in their backyards or rooftops without the need for spacious farmland. The aquaponics integrated with bio-floc is also more environmentally friendly owing to its lower water consumption as a result of its zero or minimal water exchange during the operation. Legislators and policymakers can help to promote aquaponics as part of sustainable urban food production that can solve global food security issues.

CONCLUSION

The half-nutrient treatment showed better products of pak choi than the full-nutrient treatment on all measured variables (plant height, number of leaves, weight growth, stem weight, and stem height). The average growth rate of pak choi in the half-nutrient treatment was around 17.12% better than that in the full-nutrient treatment. This result indicates that the additional Fe, Ca, and K nutrients can compensate for the missing elements in the aquaponics system. However, as to the culture-medium treatment, there was no significant difference in the effects of rockwool, rockwool-perlite, and rockwool-husk mediums on pak choi's growth rate on every measured variable. Finally, the fish growth under the half-nutrient treatment was higher than that under the full-nutrient treatment, although the difference was not statistically significant. Further experiments with more replications should be conducted to confirm the difference.

ACKNOWLEDGEMENTS

This study was supported by the Institute for Research and Community Services of Atma Jaya Catholic University of Indonesia under Research Grant "Hibah Kompetitif 2019" No. 2019-RIA.

REFERENCES

Abd-Elmaksoud, A., Kassab, M. A., Sayed, A. A., & Fayed, M. H. (2008). Anatomical, light and scanning electron microscopic studies on the air breathing dendretic organ of the sharp tooth catfish (*Clarias gariepinus*). *Journal of Veterinary Anatomy*, *1*(1), 29–37. https://doi.org/10.21608/jva.2008.45452

Afolabi, K. A. (2020). *Productivity of kale (*Brassica oleracea *var.* acephala*) and Nile tilapia (*Oreochromis niloticus*) culture in aquaponic systems* [Master's thesis, The American University in Cairo]. AUC Knowledge Fountain. https://fount.aucegypt.edu/etds/1449/

Ahmad, I., Babitha Rani, A. M., Verma, A. K., & Maqsood, M. (2017). Biofloc technology: An emerging avenue in aquatic animal healthcare and nutrition. *Aquaculture International*, *25*, 1215–1226. https://doi.org/10.1007/s10499-016-0108-8

Akasiska, R., Samekto, R., & Siswadi. (2014). Pengaruh konsentrasi nutrisi dan media tanam terhadap pertumbuhan dan hasil sawi pakcoy (*Brassica parachinensis*) sistem hidroponik vertikultur [The effect of nutrient concentration and growing media on the growth and yield of mustard pak choi (*Brassica parachinensis*) in verticulture hydroponic system]. *Jurnal Inovasi Pertanian*, *13*(2), 46–61.

Belão, T. C., Zeraik, V. M., Florindo, L. H., Kalinin, A. L., Leite, C. A. C., & Rantin, F. T. (2015). Control of cardiorespiratory function in response to hypoxia in an air-breathing fish, the African sharptooth catfish, *Clarias gariepinus*. *Comparative Biochemistry and Physiology*

Part A: Molecular and Integrative Physiology, *187*, 130–140. https://doi.org/10.1016/j.cbpa.2015.05.010

Bittsanszky, A., Uzinger, N., Gyulai, G., Mathis, A., Junge, R., Villarroel, M., Kotzen, B., & Komives, T. (2016). Nutrient supply of plants in aquaponic systems. *Ecocycles*, *2*(2), 17–20. https://doi.org/10.19040/ecocycles.v2i2.57

Campbell, S. M., Anderson, S. L., Brym, Z. T., & Pearson, B. J. (2021). Evaluation of substrate composition and exogenous hormone application on vegetative propagule rooting success of essential oil hemp (*Cannabis sativa* L.). *PLOS One*, *16*(7), e0249160. https://doi.org/10.1371/journal.pone.0249160

da Rocha, A. F., Filho, M. L. B., Stech, M. R., & da Silva, R. P. (2017). Lettuce production in aquaponic and biofloc systems with silver catfish. *Rhamdia quelen*. *Boletim do Instituto de Pesca*, *44*, 64-73. https://doi.org/10.20950/1678-2305.2017.64.73

Echer, M. M., Dalastra, G. M., Hachmann, T. Lo, Klosowskı, E. S., & Guimarães, V. F. (2015). Agronomic performances of pak choi grown with different soil cover. *Horticultura Brasileira*, *33*(2), 261–266. https://doi.org/10.1590/S0102-053620150000200020

Ewert, F. (2004). Modelling plant responses to elevated CO_2: How important is leaf area index? *Annals of Botany*, *93*(6), 619–627. https://doi.org/10.1093/aob/mch101

Fimbres-Acedo, Y. E., Servín-Villegas, R., Garza-Torres, R., Endo, M., Fitzsimmons, K. M., Emerenciano, M. G. C., Magallón-Servín, P., López-Vela, M., & Magallón-Barajas, F. J. (2020). Hydroponic horticulture using residual waters from *Oreochromis niloticus* aquaculture with biofloc technology in photoautotrophic conditions with *Chlorella* microalgae. *Aquaculture Research*, *51*(10), 4340–4360. https://doi.org/10.1111/are.14779

Gallardo-Collí, A., Pérez-Rostro, C. I., & Hernández-Vergara, M. P. (2019). Reuse of water from biofloc technology for intensive culture of Nile tilapia (*Oreochromis niloticus*): Effects on productive performance, organosomatic indices and body composition. *International Aquatic Research*, *11*, 43–55. https://doi.org/10.1007/s40071-019-0218-9

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K. V, Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability*, *7*(4), 4199–4224. https://doi.org/10.3390/su7044199

Grusak, M. A. (2001). Plant macro- and micronutrient minerals. In *eLS*. https://doi.org/https://doi.org/10.1038/npg.els.0001306

Harborne, J. B. (1998). *Phytochemical methods: A guide to modern techniques of plant analysis* (3rd ed.). Springer.

Harmon, T. S. (2005). The role of “aquaponics” in recirculating aquaculture systems. *International Journal of Recirculating Aquaculture*, *6*(1), 13–22. https://doi.org/10.21061/ijra.v6i1.1398

Ingram, D. L., Henley, R. W., & Yeager, T. H. (2003). *Growth media for container grown ornamental plants*. https://ufdc.ufl.edu/IR00004607/00001/pdf

Kasozi, N., Tandlich, R., Fick, M., Kaiser, H., & Wilhelmi, B. (2019). Iron supplementation and management in aquaponic systems: A review. *Aquaculture Reports*, *15*, 100221. https://doi.org/10.1016/j.aqrep.2019.100221

Kaudal, B. B., Chen, D., Madhavan, D. B., Downie, A., & Weatherley, A. (2016). An examination of physical and chemical properties of urban biochar for use as growing media substrate. *Biomass and Bioenergy*, *84*, 49–58. https://doi.org/10.1016/j.biombioe.2015.11.012

Kearney, J. (2010). Food consumption trends and drivers. *Philosophical Transactions of the Royal*

Society B: Biological Sciences, *365*, 2793–2807. https://doi.org/10.1098/rstb.2010.0149

Nozzi, V., Graber, A., Schmautz, Z., Mathis, A., & Junge, R. (2018). Nutrient management in aquaponics: Comparison of three approaches for cultivating lettuce, mint and mushroom herb. *Agronomy*, *8*(3), 27. https://doi.org/10.3390/agronomy8030027

Ogello, E. O., Musa, S. M., Mulanda Aura, C., Abwao, J. O., & Mbonge Munguti, J. (2014). An appraisal of the feasibility of tilapia production in ponds using biofloc technology: A review. *International Journal of Aquatic Science*, *5*(1), 21–39.

Oladimeji, A. S., Olufeagba, S. O., Ayuba, V. O., Sololmon, S. G., & Okomoda, V. T. (2020). Effects of different growth media on water quality and plant yield in a catfish-pumpkin aquaponics system. *Journal of King Saud University - Science*, *32*(1), 60–66. https://doi.org/10.1016/j.jksus.2018.02.001

Palm, H. W., Knaus, U., Appelbaum, S., Goddek, S., Strauch, S. M., Vermeulen, T., Haïssam Jijakli, M., & Kotzen, B. (2018). Towards commercial aquaponics: A review of systems, designs, scales and nomenclature. *Aquaculture International*, *26*, 813–842. https://doi.org/10.1007/s10499-018-0249-z

Pattilo, D. A. (2017). *An overview of aquaponic system: Hydroponic component*. https://www.ncrac.org/files/publication/hyroponic_components.pdf

Pinho, S. M., de Lima, J. P., David, L. H., Emerenciano, M. G. C., Goddek, S., Verdegem, M. C. J., Keesman, K. J., & Portella, M. C. (2022). FLOCponics: The integration of biofloc technology with plant production. *Reviews in Aquaculture*, *14*(2), 647–675. https://doi.org/10.1111/raq.12617

Popoola, O. M., Oguntade, S. T., & Adebayo, O. T. (2021). Growth performance and immunological response of African catfish (*Clarias gariepinus*) juveniles reared in biofloc system. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, *122*(1), 137–145. https://doi.org/10.17170/kobra-202105253967

Prayogo., Agustono., Rahardja, B. S., & Amin, M. (2021). Growth performance and nutrient composition of mustard green (*Brassica juncea*) cultured in aquaponics systems and hydroponic system. *Journal of Aquaculture and Fish Health*, *10*(3), 373–379. https://doi.org/10.20473/jafh.v10i3.26593

Priadi, D., Wibowo, H., & Mulyaningsih, E. S. (2019). The growth optimization of pak choy (*Brassica rapa* L. var. *chinensis*) in household-scale aquaponics system. *Jurnal Biodjati*, *4*(2), 175–183. https://doi.org/10.15575/biodjati.v4i2.4630

Resh, H. M. (2015). *Hydroponics for the home grower* (1st ed.). CRC Press. https://doi.org/10.1201/b18069

Saba, G. K., & Steinberg, D. K. (2012). Abundance, composition, and sinking rates of fish fecal pellets in the Santa Barbara Channel. *Scientific Reports*, *2*, 716. https://doi.org/10.1038/srep00716

Sarmento, R. L. T., Hakim, R. R., & Hermawan, D. (2020). The effect of AB Mix nutrition on growth performance of catfish (*Clarias gariepinus*) and lettuce (*Lactuca sativa*) cultivated in aquaponic systems. *Indonesian Journal of Tropical Aquatic*, *3*(2), 87–94.

Sastro, Y. (2015). Akuaponik: Budidaya tanaman terintegrasi dengan ikan, permasalahan keharaan dan strategi mengatasinya [Aquaponics: Integrated plant farming with fish, nutritional problems and strategies to overcome them]. *Buletin Pertanian Perkotaan*, *5*(1), 33–42.

Setiadi, E., Taufik, I., Widyastuti, Y. R., Ardi, I., & Puspaningsih, D. (2019). Improving productivity and water quality of catfish, *Clarias* sp. cultured in an aquaponic ebb-tide system using different filtration. In *IOP Conference*

Series: Earth and Environmental Science (Vol. 236, No. 1, p. 12026). IOP Publishing. https://doi.org/10.1088/1755-1315/236/1/012026

Sundar, L. S., & Chen, G. S. (2020). Study on the growth performance of lettuce (*Lactuca sativa*) and pak choi (*Brassica chinensis*) in different aquaponic growing systems. *Horticulturae*, *6*(4), 69. https://doi.org/10.3390/horticulturae6040069

Zhang, H., Gao, Y., Shi, H., Lee, C. T., Hashim, H., Zhang, Z., Wu, W.-M., & Li, C. (2020). Recovery of nutrients from fish sludge in an aquaponic system using biological aerated filters with ceramsite plus lignocellulosic material media. *Journal of Cleaner Production*, *258*, 120886. https://doi.org/10.1016/j.jclepro.2020.120886