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Nursery of red tilapia *Oreochromis niloticus* in a small-scale aquaponics system with different stocking densities

Pendederan ikan nila merah *Oreochromis niloticus* pada sistem akuaponik dengan padat penebaran berbeda

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ABSTRACT

Aquaponics is a fish and hydroponic plant-rearing system that utilises fish waste as a plant nutrient. Because water quality can be maintained at an optimal level for fish in the system to enhance farming productivity. This study was conducted to evaluate the effects of fish density on the nursery stage of red tilapia in a small-scale aquaponic system. The study was conducted using a completely randomized design at three levels of stocking density, namely 250 fish/m^2, 375 fish/m^2, and 500 fish/m^2 of red tilapia at an initial size of 6.8 ± 0.35 cm, with 30 net pots of bok choy plant as co-culture. The results that the increase in fish population escalated the productivity of both fish and vegetable in 30 days farming period. The stocking density did not affect fish survival 99 ± 0.82%, 97 ± 1.27%, and 97 ± 0.68%, respectively ($p>0.05$), but supported a better specific growth rate, namely 3.09 ± 0.30%/day; 3.57 ± 0.23%/day; 4.03 ± 0.04%/day ($p<0.05$). Interestingly, the smallest coefficient of diversity and lowest feed conversion ratio were obtained at 500 fish/m^3, whereas absolute length growth did not differ. Bok choy production increased with fish density, namely 2.82 ± 0.06 kg; 2.88 ± 0.08 kg; 3.17 ± 0.10 kg, respectively ($p<0.05$). The water quality parameter values were almost identical in all treatments, except for the lowest bacterial abundance gained at stocking density of 500 fish/m^3. In conclusion, the aquaponic system can be used to nurseries tilapia seeds at high stocking densities for production efficiency.

Keywords: aquaculture, bok choy, hydroponics, intensification

ABSTRAK

Akuaponik adalah sistem pemeliharaan ikan dan tanaman hidroponik yang memanfaatkan kotoran ikan sebagai nutrisi tanaman. Karena kualitas air dapat dipertahankan pada tingkat optimal untuk ikan dalam sistem akuaponik untuk meningkatkan produktivitas budidaya. Penelitian ini dilakukan mengevaluasi pengaruh peningkatan kepadatan ikan pada tahap pendederan ikan nila merah dalam sistem akuaponik skala kecil. Penelitian dilakukan dengan menggunakan rancangan acak lengkap pada tiga tingkat kepadatan tebar yaitu 250 ekor/m^2, 375 ikan/m^2, dan ikan nila merah sebanyak 500 ekor/m^2 dengan ukuran awal 6,8 ± 0,35 cm, pada masing-masing sistem aquaponik dengan 30 net pot tanaman bok choy. Hasil penelitian menunjukkan peningkatan populasi ikan telah meningkatkan produktivitas ikan dan sayuran dalam masa budidaya 30 hari. Peningkatan padat penebaran tidak berpengaruh terhadap kelangsungan hidup ikan yaitu berturut-turut sebesar 99 ± 0,82%, 97 ± 1,27%, dan 97 ± 0,68% ($p>0,05$), namun mampu mendukung laju pertumbuhan spesifik yang lebih baik yaitu 3,09 ± 0,30%/hari; 3,57 ± 0,23%/hari; dan 4,03 ± 0,04%/hari ($p<0,05$). Menariknya, koefisien keanekaragaman terkecil dan rasio konversi pakan terendah diperoleh pada kepadatan 500 ekor/m^3, sedangkan pertumbuhan panjang absolut tidak berbeda. Produksi bok choy meningkat seiring dengan kepadatan ikan yaitu berturut-turut 2,82 ± 0,06 kg; 2,88 ± 0,08 kg; 3,17 ± 0,10 kg, ($p<0,05$). Nilai parameter kualitas air hampir sama pada semua perlakuan, kecuali kelimpahan bakteri terendah diperoleh pada padat tebar 500 ekor/m^3. Secara keseluruhan, produksi ikan dan tanaman tertinggi terdapat pada kepadatan penebaran 500 ekor/m^3. Kesimpulannya, sistem akuaponik dapat digunakan untuk pembibitan benih ikan nila dengan padat tebar tinggi untuk efisiensi produksi.

Kata kunci: akuakultur, hidroponik, intensifikasi, pak coy

INTRODUCTION

Tilapia fish farming in Indonesia is divided into three successive sessions, namely hatchery, nursery, and enlargement, each of which can be carried out by different actors in an attempt to generate income. The first two stages play an important role in the fish seed supply as input in the third stage by meeting the criteria for the right quantity, quality, and delivery time beneficial to the grow-out until harvest. The hatchery business usually focuses on the production of 0.9-1.3 cm seeds from brood spawning to be sold on the seed market. The nursery business raises seeds from the hatchery to obtain larger seed sizes which ready for stocking in grow-out ponds. There are three tilapia nursery stages each to produce three sizes of fish at 3-5 cm, 5-8 cm, and 8-12 cm respectively (BSN, 2009).

Nursery activities are businesses that can be carried out on limited capital and land because they require simple facilities with a short cultivation time and can be carried out on a small scale at the household level. The nursery of tilapia is mostly done in pond systems at a low stocking rate of 25 fish/m^2, but it can also be done in cages with a high stocking density of 1000 fish/m^2 with both system resulting in 70-80% fish survival (BSN, 2009). Mass production of tilapia seed need to be increased in order to meet its market growth considering Indonesia's tilapia production has reached 1.35 billion tons with a value of IDR 33.62 trillion in 2021. This amount has increased by 9.63% compared to the previous year which was 1.23 billion tons with a value of IDR 29.19 trillion (KKP, 2022).

Small-scale aquaculture systems can contribute significantly to food and nutritional security, poverty alleviation, and rural development, especially in developing countries. Furthermore, most small-scale farms tend to rely on traditional technologies and do not seek technological change owing to multiple constraints (Belton *et al.*, 2018). Currently, there is growing interest in small-scale aquaponic systems. Aquaponics is an intensive fish-vegetable production system that combines aquaculture with the production of plants in a hydroponic system. Aquaponics can be set up in different ways, but the basic principle is that fish are raised in tanks, and part or all of the wastewater containing excreted nutrients is then circulated to the hydroponic plant production system.

Plants take up water and nutrients, thereby cleaning the water and circulating it back into the fish tanks. Aquaponics is a type of RAS in which water filtration technology allows the reuse of rearing water for fish production with the integration of hydroponics. The basic principle of aquaponic farming is that fish are raised in tanks, and part or all the wastewater containing excreted nutrients is then circulated to the hydroponic plant production system. The plants take up the water and nutrients, thereby cleaning the water and circulated back into the fish tanks. Small-scale aquaponics have been popular worldwide for many decades, have a high public profile, and are well suited to urban environments to produce fresh and high-quality food in small spaces (Junge *et al.*, 2017).

These systems can be located within cities; for example, they can be located in parks, urban gardens, buildings, houses, courtyards, and on rooftops. There are three general types of systems: raft or deep water culture systems, nutrient film systems, and systems based on media-filled beds. Raft culture is typically preferred for commercial operations, whereas the nutrient film technique (NFT) used for hydroponics is restricted to certain types of plants (such as leafy green vegetables) that do not have large, heavy root systems. Aquaponic systems can be used for intensive production because they are equipped with reliable facilities to maintain good water quality and are suitable for fish farming at zero or minimum water exchange. The unique requirements of aquaponics can create technical, economic, and even cultural constraints and opportunities; therefore, it is necessary to explore whether it is feasible to produce fish at the household scale.

As a modern fish farming production system combined with hydroponic plants, aquaponics makes optimal use of the functions of water and space in a cultivation unit, does not require fertiliser, is very efficient in water use and high productivity, and produces two products simultaneously, that is, organic plants and fish (Somerville *et al.*, 2014). From an aquaculture perspective, aquaponic technology is the development of a recirculation system that combines fish and plant maintenance as a solution to the problem of hazardous nitrogen waste in intensive fish farming using plants that utilise nitrogen waste for growth (Goddek *et al.*, 2019). There are various types of plants used in aquaponic systems, one of which is the bok choy plant (Brasicca rapa supsp. chinensis). The edible portion of 100 g bok choy contains 1.7 g protein, 0.2 g fat, 3.1 g carbohydrates, vitamins and minerals such as β-carotene (2.3 mg), vitamin C (53 mg) and calcium (102 mg) (Tay & Toxopeus, 1994). The plants could reach weights of 110 and 95 g/plant 60 days after planting (Yudhistira *et al*., 2014). Bok choy plant roots can reach 30 cm in length, with a proportion of 15-22% of plant biomass (Kano *et al*., 2021).

Bok choy plants function as phytoremediators in waters because of their ability to absorb dissolved organic matter, especially free nitrogen compounds in waters through plant roots up to 96.62% (Effendi *et al*., 2015) and are considered the most effective vegetable plant to restore water qualities (Damanik *et al*., 2018). Instead of adding fertilizer to the water to provide nutrients for hydroponics vegetables, fish in aquaponics provide a natural source of organic nutrition for vegetables and are considered to be of better quality compared to hydroponics vegetables because they do not use synthetic fertilizers and deserve a better price. It seems that the nutrients provided by waste from tilapia culture resulted in a higher fresh weight of bok choy, as reported by Estim *et al*. (2019). In order to get the maximum benefit from land use which then has an impact on the profitability of aquaculture, stocking density is a parameter that affects productivity through growth rate and fish survival.

There are positive and negative relationships between stocking density and fish growth, which are usually species-specific. Love *et al*. (2015) found that tilapia were the fish species that were commonly raised in aquaponic systems, whereas the commonly grown crops were high-value vegetables and herbs such as basil, lettuce, tomatoes, salad greens, kale, chard, bok choy, peppers, and cucumbers. The tilapia nursery stage in aquaponic systems can be more effective because it can maintain water quality and facilitate the monitoring of fish populations. At appropriate stocking densities before reaching carrying capacity, fish can grow well (Ronald *et al*., 2014), but when fish are stocked at higher stocking densities, fish growth decreases along with increasing size variations due to intraspecific competition.

Considering that the rearing period for tilapia is about 30 days shorter than the rearing period which is around 3-4 months, an increase in fish density has the opportunity to enhance productivity. In conventional pond systems, the stocking density of tilapia seeds measuring 3-4 cm is 50 fish/m^2 (BSN, 2009), whereas that of intensive tilapia cultivation using an aquaponics system is 150 fish/m^2 (Zalukhu *et al*., 2016). The tilapia nursery stage using aquaponics system is expected to be more effective because it can reduce water use, maintain water quality and facilitate population monitoring. For a shorter nursery period compared to grow out period, it is possible to increase the stocking density to make the production units more efficient.

The very small size of aquaponics farms would seem to indicate that most are operated as a type of lifestyle choice or hobby, returning perhaps some supplemental revenue, rather than as full-time aquaculture businesses. Aquaponic systems have different types and levels of costs and returns. Very conservative estimates must be used, particularly for the pounds of fish that can be raised, the volume of vegetables that can be produced and the risks involved. Raising fish indoors is two to three times more expensive than raising fish in open ponds. The plan for an aquaponics business must also consider the percentage of the produce to be sold. Thus, this study aimed to analyse the effects of high stocking density on the production performance of tilapia nurseries.

MATERIALS AND METHODS

Experimental system

The experiment was conducted in a completely randomized design using three treatment levels of fish stocking densities, namely 250 individuals/m^2, 375 individuals/m^2, and 500 individuals/m^2, with three replications for each. The test fish used were red tilapia with an average length of 6.8 ± 0.35 cm and an average weight of 6.6 ± 0.54 g. Bok choy plants aged 14 days after sowing with root length 7.5 ± 0.57 cm, plant height 4.5 ± 0.14 cm, and leaf diameter 2.0 ± 0.37 cm were planted using rock wool in each net pot filled with 30 holes plant beds.

The aquaponics used are nine units of the Nutrient Film Technique system. The fish rearing tank was in the form of a round fibre tub with dimensions of 120 cm × 60 cm × 35.4 cm, filled with 400 L of fresh water. The rearing container for each treatment was equipped with aeration, a tubular filter compartment with a diameter of 20 cm and a height of 50 cm, and a 5-level vertical plant bed with a length of 60 cm each to accommodate 30 potted plants. The filter set consists of dacron (physical), activated charcoal and zeolite (chemical), and bio balls (biological) arranged in layers. Water circulation was driven using a 13 watt power pump (700 L/hour discharge) to drain water from the rearing tank into the filter tube and a 60 watt power pump (3000 L/hour discharge) to drain the filtered water into the plant compartment.

Fish are cultivated in nursery stage II for 30 days with a target harvest size of 9-10 cm. Fish were fed artificial feed with a protein content of 39-41% which was provided at satiation three times a day. Bok choy nutrition is sourced only from organic waste in fish cultivation rooms. Both products were actually harvested at the end of the experiment.

Sampling and measurements

The sample size of 30 fish for each replication was measured every ten days interval. Survival rate (SR), average length gain (ALG), average weight gain (AWG), specific growth rate (SGR), difference coefficient (CD) of fish weight and length, and feed conversion rate (FCR) were calculated as follows:

The survival rate (SR)

The survival rate of the fish was in percent (%) and calculated by this following formula:

$$SR = \frac{\text{final fish number}}{\text{initial fish number}} \times 100$$

Absolute length gain (ALG)

The fish growth was calculated according to the absolute length gain by the following formula:

$$ALG\ (cm) = L_t - L_0$$

Note:
L_t = Final average length (cm)
L_0 = Initial average length (cm)

Absolute weight gain (AWG)

The absolute weight growth was calculated by the following formula:

$$AWG\ (g) = Wt - Wo$$

Note:
Wt = Final average weight (g)
Wo = Initial average weight (g)

Specific growth rate (SGR)

The specific growth rate was counted by the following formula:

$$SGR = (Ln(Wt) - Ln(Wo)) / t$$

Note:
SGR = Daily weight growth rate (%/day)
$Ln(w_t)$ = Final average weight logarithm (g)
Ln(t) = Initial average weight logarithm (g)
t = Rearing days (day)

Coefficient of variance of fish size

The variance of fish size in this study was the fish length, stated as coefficient of variance of fish size:

$$KK\ (\%) = \frac{s}{y} \times 100$$

Note:
s = Standard deviation
y = Average length

Feed conversion ratio (FCR)

Feed conversion ratio was calculated by this following formula:

$$FCR = \frac{F}{Wt + D - Wo}$$

Note:
FCR = Feed conversion ratio
F = Total feed (g)
Wt = Final fish biomass (g)
D = Dead fish biomass (g)
Wo = Initial fish biomass (g)

Bok choy production

Plant production is measured by weight of fresh biomass. Bokchoy plant growth includes the number of leaves, leaf diameter, and root length.

Water quality measurement

The water quality parameters measured daily included temperature, dissolved oxygen (DO), and pH. While the water quality parameters measured once every 10 days are total ammonia nitrogen (TAN), nitrite and nitrate. The abundance of bacteria in the aquaponics system was calculated using the TPC (total plate count) method (Wahyuningsih *et al*., 2015). The number of bacteria is expressed in unit of CFU/mL.

Statistical analysis

Statistical analysis was performed using Microsoft Excel 2013 and SPSS 22.0 software. Data are presented as mean ± SEM. The effect of fish stocking density was analyzed by one way ANOVA with fish stocking density as the fixed variable. Differences were considered significant at $P<0.05$. All data were tested for homogeneity of variance using the Levene Statistical test, and for normality with the Kolmogorov-Smirnov and Shapiro-Wilk normality tests. Duncan's parametric test was used to assess between-group differences in these parameters from each experimental data.

Water quality data were analyzed descriptively by presenting tables. Table 1 summarizes the statistical analysis of stocking density factors on the fish performance parameters. Table 2 summarized the statistical analysis of fish stocking density factors on plants growth.

RESULTS AND DISCUSSION

Results

The increase in stocking density in the aquaponic system did not affect the SR, ALG, and WCD of tilapia, and generally showed good results in all treatments (Table 3). The high survival of

Table 1. One-way ANOVA results of stocking density factors on the survival rate (SR), absolute length growth (ALG), absolute weight growth (AWG), specific growth rate (SGR), weight coefficient diversity (WCD), length coefficient diversity (LCD), feed conversion ratio (FCR) of red tilapia *Oreochromis* sp.

Parameters	Source of Variation	SS	DF	MS	F	P
SR	SD	16.222	8	2.778	1.563	0.284
ALG	SD	0.122	8	0.020	1.425	0.312
AWG	SD	6.748	8	2.541	9.152	0.015
SGR	SD	1.756	8	0.663	9.252	0.015
WCD	SD	21.647	8	2.648	.971	0.431
LCD	SD	29.895	8	11.862	11.535	0.009
FCR	SD	0.245	8	0.098	12.167	0.008

Note: SD (stocking density); SS (sum of square); DF (degrees of freedom); F (distribution fitting); MS (mean square); P (probability).

Table 2. One-way ANOVA results of fish stocking density factors on plant biomass, the number of leaves, leaf diameter, root length of bok choy *Brassica rapa* subsp. *Chinensis*

Parameters	Source of Variation	SS	DF	MS	F	P
Plants biomass	SD	0.211	8	.105	1051.000	.0000
No. of leaves	SD	2.000	8	.000	.000	1.000
Leaf diameter	SD	2.549	8	.054	.134	.877
Root length	SD	135.842	8	.921	.041	.960

Note: SD (stocking density); SS (sum of square); DF (degrees of freedom); F (distribution fitting); MS (mean square); P (probability).

Table 3. Production performance of red tilapia *Oreochromis* sp. reared in aquaponics system with bok choy *Brassica rapa* subsp. *chinensis*.

Fish Parameters	Initial stocking density		
	250 fish/m^2	375 fish/m^2	500 fish/m^2
SR (%)	99.0 ± 0.82^{a}	97.0 ± 1.27^{a}	97.0 ± 0.68^{a}
ALG (cm)	2.7 ± 0.13^{a}	2.5 ± 0.05^{a}	2.7 ± 0.09^{a}
AWG (g)	6.1 ± 0.60^{a}	7.0 ± 0.45^{ab}	7.9 ± 0.01^{b}
SGR (%/day)	3.1 ± 0.30^{a}	3.6 ± 0.23^{ab}	4.0 ± 0.04^{b}
WCD (%)	15.1 ± 0.78^{a}	13.3 ± 1.22^{a}	14.3 ± 1.83^{a}
LCD (%)	8.6 ± 0.72^{a}	4.7 ± 0.98^{b}	5.7 ± 0.76^{b}
FCR	1.0 ± 0.07^{a}	0.7 ± 0.08^{b}	0.7 ± 0.07^{b}

The different superscript at bar showed significantly different result ($P<0.05$).

fish obtained in this experiment was between 97.0 ± 1.27% and 99.00 ± 0.82% indicating that the aquaponics system is capable to support fish life in denser populations. Interestingly, an increase in stocking density can increase the AWG and SGR values of fish with better LCD and FCR values. The survival rate of bok choy in all treatments were 100%.

The increase of fish stocking density affected on plant biomass significantly (Table 4), even though value of the leaves number, leaf diameter and root length were not affected by treatments applied. During the rearing period, the water quality values for all treatments were within the optimal range (Table 5), whereas the bacterial count tended to be lower. The water temperature around 26°C can withstand oxygen levels up to higher than 7 ppm. As shown in Figure 1, the values of ammonia, nitrite, and nitrate had the same values and patterns in all treatments.

Ammonia and nitrite levels during the rearing period were very low at less than 0.1 mg/L. Table 6 shows that fish density affects the ratio of harvest value and income from the sale of fish

Table 4. Production performance of bok choy *Brassica rapa* subsp. *chinensis* reared in aquaponic system with nile tilapia *Oreochromis niloticus* (Linnaeus, 1758).

Plant Parameters	Initial stocking density		
	250 fish/m^2	375 fish/m^2	500 fish/m^2
Plant biomass (kg)	2.8 ± 0.06^{a}	2.9± 0.08^{b}	3.2 ± 0.10^{c}
No. of leaves	14.0 ± 0.85^{a}	14.0 ± 1.11^{a}	14.0 ± 0.97^{a}
Leaf diameter (cm)	5.5 ± 1.01^{a}	5.4 ± 0.94^{a}	5.6± 0.78^{a}
Root length (cm)	23.0 ± 6.11^{a}	22.3 ± 4.14^{a}	23.4 ± 5.33^{a}

The different superscript at bar showed significantly different result (P<0.05).

Table 5. Water quality level during 30 days rearing of red tilapia *Oreochromis* sp.using aquaponics system with bok choy *Brassica rapa* subsp. *chinensis*.

Parameter	Initial stocking density			Optimal range
	250 fish/m^2	375 fish/m^2	500 fish/m^2	
Temperature (°C)	26.4 ± 0.6	26.2 ± 0.5	26.3 ± 0.5	24-33^{a}
DO (mg/L)	7.9 ± 0.5	8.0 ± 0.5	7.9 ± 0.5	>5^{b}
pH	7.4 ± 0.3	7.4 ± 0.3	7.6 ± 0.3	6.0-7.5^{b}
Bacterial count (CFU/mL)	3.31×10^{7}	1.06×10^{8}	1.36×10^{6}	10^{8}–10^{12}^{c}

Note: a) Panggabean *et al*., 2016; b) Somerville *et al*., 2014; c) Hu *et al*., 2015

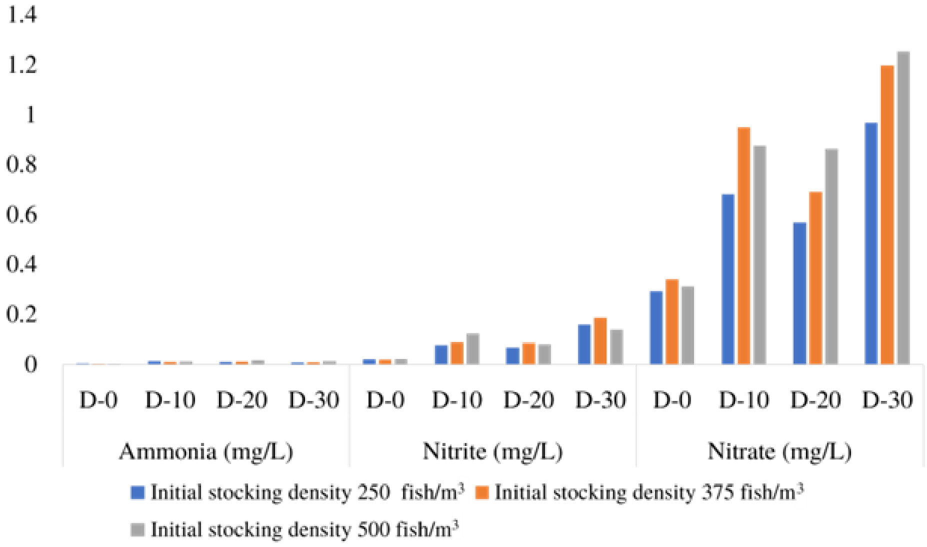

Figure 1. Ammonia, nitrite and nitrate values for 30 days of rearing red tilapia *Oreochromis* sp. using aquaponics system with bok choy *Brassica rapa* subsp. chinensis.

and vegetables produced. Enhancing fish density from 250 fish/m^3 to 500 fish/m^3 could increase total income by 1.72 times as the fish harvest rate almost doubled. Income from vegetables is lower than selling fish since the number of plant pots remains the same even though fish stocks are increased.

Discussion

At aquaponics system, fish stocking density plays an important role for the functioning of the system and must be optimal to maintain water quality suitable for fish and availability of nutrients for plant growth. Considering the high survival rate obtained in this study, the productivity of aquaponic systems could be increased by increasing the stocking density of fish. A two-fold increase in fish stocking density resulted highest productivity at 1.96 times on fish and 1.14 times on vegetables. Better growth rates and feed utilization gained at high stocking densities when compared to low stocking densities also found on juvenile of meagre Argyrosomus regius (Millan-Cubillo *et al*., 2016).

The application of three levels fish stocking density counted more efficient use of water for nursery activities, namely 1.6, 1.1 and 0.9 L per fish respectively and reduced the amount of water for fish farming. Aquaponics are the most productive food systems in terms of water use efficiency because recirculating aquaculture (RAS) systems use 90–99 percent less water than other aquaculture systems (Timmons & Ebeling, 2007). The critical point in the limited water volume of aquaculture, such as decreasing the quality of water originating from fish waste, did not occurred in this study. Ammonia concentration in the aquaponics system studied was quite low, 0.0033-0.0184 mg/L, compared to the ammonia level in the recirculating aquaculture system, as found at 0.07 ± 0.05 mg/L (Gullian-Klanian & Adame, 2013). According to Azhari and Tomasoa (2018), the maximum ammonia level in an aquaponics system for rearing tilapia is less than 0.5 mg/L. The accumulation of uneaten food, excrement, and organic compounds and nitrogen in the biofilter provides an adequate environment for microbial development.

High fish densities can trigger an increase in fish metabolic waste and decomposed feed residue. Ammonia production occurs in waters which will disrupt fish life and have an impact on fish survival and growth, but if the system works well to prevent water quality degradation, high growth and survival can be produced. Ammonia is more toxic to aquatic organisms at high temperatures and pH values. As the pH increases, so does the fraction of un-ionized ammonia and its toxicity to fish. The ratio of NH3 to NH4+ increases 10-fold for every one-unit increase in pH, and about 2-fold for every 10oC increase in temperature from 0-30oC (EPA, 2009).

The pH value for 30 days of nursery experiments ranged from 7.1 to 7.9, the same as the optimal pH value in the aquaponics system was 6-7.5 and the optimal growth of nitrifying bacteria was at pH 6.0-8.5 (Somerville *et al*., 2014). Ammonia produced by fish can be removed by bacterial conversion of ammonia to nitrites and nitrates. Nitrates can be used by plants and are generally considered harmless to fish in natural waters. The value of nitrite (NO2-) during rearing of tilapia fry in an aquaponics system ranged from 0.0197-0.1873 mg/L, and was classified as low according to the opinion of Somerville *et al*. (2014), who stated that the optimal tolerance value for water nitrite in an aquaponics system is less than 1 mg/L. Nitrification is affected by the abundance of AOB bacteria (ammonia oxidizing bacteria) and NOB (nitrite oxidizing bacteria) (Hu *et al*., 2015) under aerobic conditions of water and plant roots in an aquaponics system.

Table 6. Increase rate of harvest and sale values red tilapia *Oreochromis* sp and bok choy *Brassica rapa* subsp. *chinensis* at different fish densities.

Description	Fish density		
	250 fish/m^2	375 fish/m^2	500 fish/m^2
Fish density increase rate	1.00	1.50	2.00
Harvest number increase rate	1.00	1.47	1.96
Revenue increase rate on fish sale	1.00	1.47	1.96
Revenue increase rate on vegetables sale	1.00	1.04	1.14
Total revenue increase rate	1.00	1.34	1.72

The end product of the nitrification process by AOB and NOB bacteria is a nitrate compound. The range of nitrate concentration during the experiment was 0.2929-1.2517 mg/L. According to Somerville *et al*. (2014), the threshold value for nitrate in an aquaponics system is less than 100 mg/L. Nitrate is used as a nutrient for plant growth. Nitrate dissolves easily in water, tends to be stable and harmless to fish and plants (Somerville *et al*., 2014). The abundance of nitrifying bacteria in an aquaponics system is influenced by the surface area of plant roots, the time of cultivation, and the availability of nutrients in the rearing water (Hu *et al*., 2015).

The optimal abundance of nitrifying bacteria (AOB and NOB) in an aquaponics system is 108-1012 CFU m/L (Hu *et al*., 2015), whereas in this study the abundance of water bacteria only reached 106–108 CFU m/L. However, according to Wahyuningsih *et al*. (2015) the abundance of bacteria in an aquaponics system of 106 CFU/mL has provided good growth performance for tilapia and plants. The low values of ammonia, nitrite and nitrate in this experiment means that there is no accumulation of these compounds resulting from the decomposition of organic fish waste because they continue to be decomposed and absorbed by growing plants. The oxygen requirement of aerobic nitrifying bacteria to grow, reproduce and carry out the nitrification process was accommodated in this experiment, namely in the range of 7-8 mg/L.

The DO concentration in this study was associated with a low water temperature of 26-27 °C. According to Somerville *et al*. (2014), the optimal DO value in freshwater tropical fish aquaponics systems is more than 5 mg/L at 18-30 °C. Bok choy plants in an aquaponics system are useful in improving the quality of fish rearing water. This plant is able to reduce ammonium in waters up to 96.62% and utilize nitrate as a source of nutrition for growth (Effendi *et al*., 2015).

The plant root functions as a nutrient absorber in waters (Effendi *et al*., 2015) and a habitat for nitrifying bacteria (Hu *et al*., 2015). This system is cost-effective and efficient in removing toxic waste from water, resulting in improved water quality for recirculating aquaculture systems. This reflects the effectiveness of bio filtration which is currently assessed by its ability to completely remove ammonia while minimizing nitrite formation (Estim *et al*., 2019). Tokunaga *et al*. (2015) investigated the economics of aquaponics production and found that small-scale farms were profitable, indicating that aquaponics may be a viable option to produce vegetables and fish to local markets.

Baker (2010) also analyzed an integrated tilapia and lettuce production system and found it to be technically feasible and profitable. In this research, tilapia nursery can be carried out using aquaponics system by applying a higher fish density compared to ponds and providing higher survival rate of the fish to generate higher revenue. Babatunde *et al*. (2021) stated that a minimum income model of 30% to 70% fish-to-plant ratio by adopting crop cultivation techniques is optimized to achieve economies of scale and viability.

CONCLUSIONS

As aquaponics are free from chemical fertilizers and crop protection chemicals, with fish waste serving as the prime nutrients for plants, the demand for organically grown crops holds high potential and an untapped space for emerging aquaponic farms and aquaponic system providers. Producing tilapia fry in an aquaponics system can be carried out at higher fish stocking densities than pond systems. Along with bok choy plant as a co-product in intensive aquaculture could increase income of small scale aquaponics. Fish as the main product indicates that sales of fish seeds provide the largest contribution to total revenue. However, the production of fish and vegetables in an aquaponics system can be useful as a support for family food security by producing healthful organic fish and vegetables.

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