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GROWING OF GREEN CORAL LETTUCE AND RED HYBRID TILAPIA IN COMPACT AQUAPONIC PROTOTYPE AT DIFFERENT RECIRCULATION RATES

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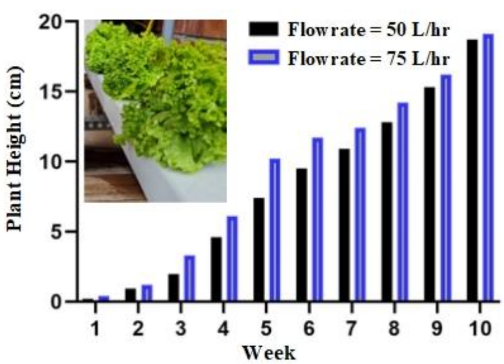
Graphical abstract



Abstract

In this work, a compact-size aquaponics prototype was designed and fabricated. One of the current challenges in compact aquaponics systems is optimizing the balance between fish waste production and plant nutrient uptake. The objective of the work is to assess the impact of different pump recirculation rates on the crops cultivation at such compact aquaponics unit. Main components included a 50 litres fish tank, a filter unit that combines the mechanical filter and biological filter counterparts, and nutrient film technique (NFT) grower. Production of food was carried out for 10 weeks at two different recirculation rates i.e. at 50 L/hr and 75L/hr. According to the data attained, the specific growth rate (SGR) was around 5.4-5.7% with a food conversion ratio (FCR) of about 1.8-2. Moreover, the fish survival rate was 80%, and plant growth yield is about 1.5-2 cm/week. Although the level of ammonia was slightly off the acceptable limit, no yellowish colour on the leaves of the green coral lettuce was observed. The data attained signify the successful operation of compact-size aquaponics for the production of organic leafy plants and freshwater aquaculture.

Keywords: Aquaponics, green salad, aquaculture, Tilapia, sustainability

Abstrak

Di dalam kertas kerja ini, prototaip akuaponik bersaiz-padat telah direkabentuk dan difabrikasi. Salah satu cabaran dalam akuaponik bersaiz-padat ialah keseimbangan optimal antara penghasilan sisa ikan dan pengambilan nutrisi oleh tumbuhan. Objektif kertas kerja ini adalah untuk menilai kesan kadar kitran pam yang berbeza terhadap penghasilan makanan dalam akuaponik bersaiz-padat. Komponen utama termasuk tangka ikan 50 liter, unit tapisan yang menggabungkan penapisan mekanikal dan penapisan biologi, dan penanaman secara teknik nutrisi filem (NFT). Pengeluaran makanan dijalankan selama 10 minggu pada dua kadar aliran yang berbeza iaitu pada 50 L.hr dan 75L/hr. Berdasarkan data yang diperolehi, kadar pertumbuhan tentu (SGR) adalah dalam lingkungan 5.4-5.7& dengan nisbah pembentukan makanan (FCR) sebanyak 1.8-2. Kadar kebolehhidupan ikan adalah 80% dan pertumbuhan pokok adalah dalam 1.5-2 cm/minggu. Walaupun aras ammonia sedikit tinggi dari had yang dibenarkan, tiada kelihatan sebarang warna kekuningan pada sayuran salad hijau. Data yang dijana menunjukkan keberkesanan operasi akuaponik bersaiz-padat dalam penghasilan sayuran organik dan hasil akuakultur yang segar.

Kata kunci: Akuaponik, salad hjau, akuakultur, Tilapia, kelestarian.

1.0 INTRODUCTION

Aquaponics is a modern and eco-friendly method of farming that combines raising fish and growing plants simultaneously within a single platform [1]. The system recirculates water into both subsystems, allowing the bacterial community to convert fish waste into valuable nitrate compounds that plants can absorb. This process helps to remediate the water from toxic ammonia compounds without using chemicals and pesticides [1-2]. Compared to traditional agriculture, aquaponics requires only a fraction of the water, with less than 10% of water being consumed and only 1-3% needing to be replenished daily [3]. These features make aquaponics a promising solution to issues related to food security. Considering the urban environment, aquaponics can be an intriguing option for food production. This is because aquaponics is an ideal small-scale (~footprint 2-5m^2) and affordable food production method that can be incorporated into limited spaces such as a home's backyard, a building's roof, or even an urban vegetable-fish indoor garden [4-5].

Several types of small-scale aquaponics platforms have been proposed that meet the criteria for urban agriculture, with the main difference between each design being the hydroponic counterpart used in each system [5-7]. Cabanas et al. [5] studied crop yield in three different types of small-scale aquaponics systems, e.g. floating rafts and horizontal and vertical systems using nutrient film technology (NFT) to combine goldfish and lettuce production. A biofilter unit and a clarifier (for solid residue removal) have been placed between the fish tanks and the crop-growing area. The footprint for each setup is between 2 m^2 and 3 m^2. The survival rate of the fish was relatively high, exceeding 90%. Plant yield per unit area varied between 0.5 and 3.4 kg m^{-2}, depending on the type of hydroponics used. Simeonidou et al. [6] constructed a modular aquaponics system consisting of a 200-litre fish tank and a rectangular 25-litre NFT channel as a hydroponic counterpart. The NFT component was positioned over the fish tank and filled with perlite to act as a filter and substrate for nitrification. Nile tilapia were grown alongside lettuce and basil, and the plants began to thrive once the nitrate level was stabilized (i.e. at levels below 2 mg L^{-1} for ammonia). Zainal Alam et al. [7] built a backyard aquaponics system utilizing a 1000-litre fish tank, which was further integrated with four rectangular tanks to provide ample space for plant growth. The plants were grown in polybags filled with coconut palms and rice husks as substrates. The system occupies an area of about 4.5 m^2 and includes biofilters containing bio-balls and bio-rings for bacterial nitrification, ensuring the safety of the aquatic environment. During their study, red hybrid tilapia and longevity spinach were cultured for 12 weeks, and the results were remarkable. The fish's survival rate was an impressive 98%, while the specific growth rate (SGR) stood at 6.9% per day, and the feed conversion rate (FCR) was recorded at 1.13. This innovative system is a testament to the possibilities of sustainable aquaponics farming, which provides a unique and eco-friendly approach to food production.

Given the robust farming and cultivation platform method, this paper evaluates the compact-size (small-scale) aquaponics platform for growing green coral lettuce and red hybrid tilapia. Knowing the appropriate fish-plant combination at different local climate conditions without compromising the output is often one of the challenges in aquaponics operation [8-9]. Contrary to the standard backyard aquaponics unit, this paper brings forth the idea of a compact one. Such a conceptual aquaponic platform is to be introduced as an alternative farming method in urban areas where spaces are minimal compared to the farming conditions in rural areas. The design of the compact unit is presented, and the workability of the unit was evaluated based on its capacity to grow green coral lettuce and cultivate red hybrid tilapia. Data was taken for 10 weeks where changes in the water quality (particularly the level of ammonia and nitrates concentration) at two different residence times and the progress of the production of the crops are discussed in detail.

2.0 METHODOLOGY

Design and Construction of the Aquaponic Platform

In this work, a compact aquaponic unit was constructed. It has a footprint of approximately 1 m^2

and was designed to fit into small spaces such as apartment balconies, the backyard of a house or building rooftops. The schematic of this aquaponic unit is illustrated in Figure 1. A rectangular polyethylene storage box with dimensions of 54 cm (length) x 34.5 cm (width) x 35 cm (height) was used as the fish tank. The fish tank formed the unit's base and was filled with water up to 80% of the tank capacity, about 52 litres. The compartment for filtering consists of a combination of aquarium sponge filters and various flower-shaped bio-balls. It is placed approximately 1 meter above the ground and connected to both the fish tank and hydroponic grower through PVC pipes (φ20mm). A horizontal nutrient-film technique (NFT) grower approach was adopted in this setup. This aquaponics unit was constructed from two PVC pipes, each measuring 100 cm in length, 10 cm in width, and 5 cm in height. Six holes, each measuring φ45 mm, were evenly spaced along the NFT pipe for the placement of net pots. To ensure proper water circulation, a 35W submersible pump was utilized. The unit's frame was constructed with high-tensile steel and securely fastened with screws and nuts to provide a sturdy structure.

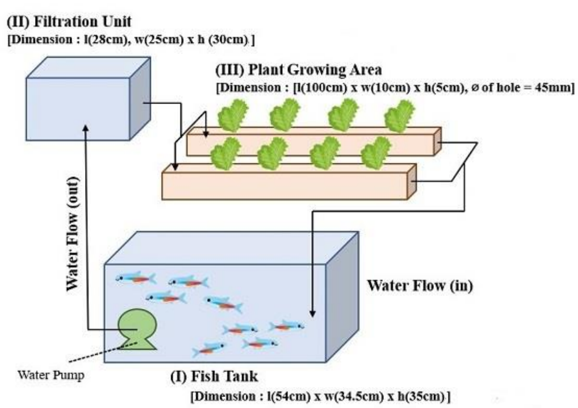


Figure 1 Schematic diagram of the compact aquaponics system developed for this study. The system consisted of a fish tank, a filtration system located between the fish tank and the plant growing area, and the NFT system for plant growing. Water is pumped from the fish tank into the filtration unit using a submersible pump and flows by gravity into the crop-growing area before flowing back into the fish tank

Seeding of Plant and Stocking of Fish

Green coral lettuce and red hybrid tilapia were cultivated to test the functionality of the proposed aquaponics unit. The paper towel germination technique was used to germinate the green coral lettuce seeds. Prior to sowing, damp sponges and lightweight expanded clay aggregate (LECA) growing media were placed in each net pot. After all net pots had been seeded with plant seeds, they were placed in the circular space designated on the NFT grower parts. The lower half of the net pots is exposed to the flowing water within the NFT grower to ensure that the plant roots remain submerged in the water during the operation.

The fish were stocked shortly after the hydroponic area was prepared. The fish tank was loaded with 10 fish with initial weight less than 50 ± 1 g. The fish tank was filled with water up to 80% of the capacity, about 52L. The fish were fed with commercial diet (Star Feed TP2) on daily basis at 20% of body weight. The study was conducted for 10 weeks.

Data Collection and Water Quality Analysis

Throughout the study, a 25 ml of water was taken from the fish tank on weekly basis in order to assess the water quality of the aquaponic unit. The pH, ammonia level, and nitrates content of the water were measured using a standard API water test kit. The colour change concept was used to measure the water sample after it was mixed with the chemicals provided [10]. Temperature of the system was measured directly from the fish tank. The API water test kit measured the Total Ammonia Nitrogen (TAN) level.

Assessment of Plant and Fish Growth Performance

The progress of the plant growth was assessed by measuring the height of the plant on weekly basis. The height of the plants was taken from leaf buds to the tips of the roots. This is to be done by carefully measure the plant height from the side of the net pot. Percentage (%) of plant height gain was calculated every week based the differences of plant height using equation 1:

$$\text{Height gain (\%)} = \frac{\text{Final height (cm)} - \text{Initial height (cm)}}{\text{Initial height (cm)}} \times 100\%$$

Growth performance of the fish was evaluated based on the fish weight. Two fish were randomly selected from the fish tank to assess the average size of fish on weekly basis. Measurements were repeated three times (triplicates). The fish were returned back to the fish tank after sufficient measurement has done [9]. Percentage (%) weight gain was estimated every week based on the differences of fish weight using the equation 2:

$$\text{Weight gain (\%)} = \frac{\text{Final weight (g)} - \text{Initial weight (g)}}{\text{Initial weight (g)}} \times 100\%$$

Fish relative growth rate (RGR) and specific growth rate (SGR) were calculated based on the differences between fish weight at the final week and fish weight at week 1 using the equation 3 and 4, respectively.

$$\text{Relative growth rate (RGR)} = \text{Weight (\%)} \,/\, \text{Duration of experiment (day)}$$

$$\text{Specific growth rate (SGR)} = \ln \frac{\text{Final weight (g)}}{\text{duration (day)}} \times 100\%$$

Finally, total food conversion ratio (FCR) for the tilapia was calculated at the end of the experiment (the 10th week of the experiment) using the following equation 5:

Food conversion ratio (FCR)
= Total feed consumed (kg) / total growth of fish (kg)

Statistical Analysis

A two-sample t test was performed to compare the means of two groups of data of interest to check whether the two group of population is different or similar to one another. The followings are the hypothesis of the t test analysis:

H0: The performance of plant growth or fish weight gain (based on the mean values) for both operating flow rates is equivalent. (null hypotheses: p value < 0.05)
H1: The performance of plant growth or fish weight gain (based on the mean values) for both operating flow rates is different. (alternative hypothesis: p value > 0.05)

The analysis was performed using Microsoft Excel two sample (assuming equal variance) option and results achieved was based on the comparison of the p-value of two tail test generated by the software with the significance level of 0.05.

3.0 RESULTS AND DISCUSSION

Justification on the Design Implemented for the Compact Aquaponics Unit

Numerous aspects were considered in designing the compact aquaponic system (Figure 2). These include the compatibility of plant and fish species, the growing area to be used, size of the fish tank, filtration unit and future maintenance. The concept of compact aquaponic system means that the setup should be small, fits within footprint of about 1-2 m^2. Due to the limited space, it is impractical to use deep water culture plant growing technique. The Nutrient Film Technique (NFT) is a smart and efficient choice for those looking for a compact setup. Not only is it cost-effective, but it also requires significantly less media bed per setup as compared to a media bed. With its efficiency, the NFT proves to be an effective solution for growing plants. Additionally, constructing and operating the NFT system is relatively easy and straightforward. The primary element of the NFT system, aside from the water reservoir or fish tank, is the plant growing tray or channel. The growing area in the NFT setup can be created using a rectangular-shaped channel or standard PVC pipes. We decided to use rectangular-shaped channels for our setup for two reasons. Firstly, it allows for easy placement of the channels into the main frame without the need for screws, bolts, or cables. Secondly, it has a flat bottom channel that allows plant roots from each net pot to have full access to the flowing water nutrient in the growing tray.

In our NFT aquaponics system, we have combined the mechanical filter part and the biological filter unit to cater for the limited space design criteria. The water inflow to the filtration unit undergoes a two-step process. Firstly, it passes through the congested carbon-based sponge-like filter, which helps in the retention of any solid residues. Then it flows into the biological filter area, specifically designed to promote nitrification. Our proposed setup uses only one pump for water circulation and aeration of the fish tank. The water will be transported directly into the filter unit, slightly above the plant growing area. The water flows smoothly into the plant-growing channel, aided by gravity. The PVC pipes connecting the outflow from the plant growing channel are slightly inclined at an angle of 30°. This enables the unused water nutrient from the plant growing area to flow directly into the fish tank, creating the necessary oxygenation action required for the aeration of the fish tank.

It is advisable to have a fish tank that is twice the size of the plant growing area. Our situation had a ratio of around 3:1, but taking water retention into account in the filtration process, it was closer to 2:1. This is essential to ensure that the water from the fish tank is adequately filtered, with a 100% conversion rate of ammonia to nitrates in one cycle. To maintain a healthy environment for the fish, we also reduced the fish stocking density to prevent an increase in ammonia levels.

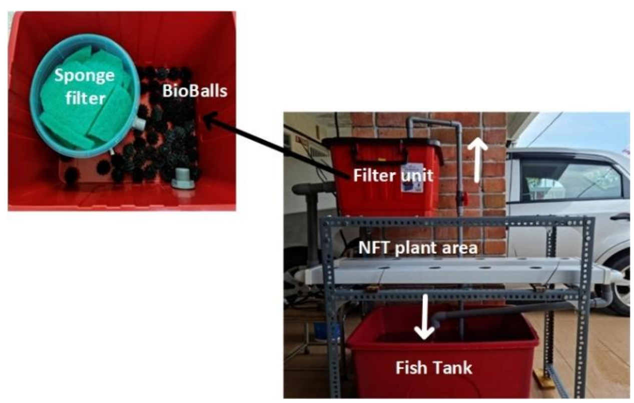


Figure 2 Image of the compact aquaponics setup designed for the present study. Inset shows the content of the filter box used for this modular setup. The footprint of the whole unit is about 2 m^2 and was setup in a home garage

Water Quality Analysis

In this study, water temperature and pH recorded were in the range of 27–30 °C and 6.4–7, respectively. This water condition attained is optimal for fish growth condition and operational of aquaponics system. [10-12]. The study involved constructing a compact aquaponics system in an open field, without any sunshading or tank insulators. The daily temperature range recorded was between 24°C and 39°C and did not affect the system's operational capacity. Although this may vary depending on the site where the system is set up. For instance, if it is placed in a garage or within a building, there may be a lack of heat from the sun.

Maintaining an appropriate pH for this compact aquaponics system can be a significant challenge. In our current system, we filled the fish tank with unchlorinated tap water, which resulted in an initial pH of 7.2-7.4. However, after running the system for several weeks, the pH has dropped and is now between 6.6 and 6.8. This could be due to the nitrifying bacteria that have developed and established in the system during the cultivation period. The bio-conversion of fish waste into usable nutrients for the plants can increase the acidity of the water. Nevertheless, the pH of the cultivation water has stabilised after 2 weeks of operation and remains in the optimal range for all living components in the aquaponics system - fish, plants and nitrifying bacteria [7, 13-14].

Figure 3 presents the profiles of the ammonia and nitrate levels during the 10-weeks cultivation period of fish and plants at different operating flowrates. The basic operation of the compact aquaponics setup in the present work involves water flowing from the fish tank into the filter unit where ammonia from the fish waste has been converted into nitrates. Then, water flows through to the hydroponic grower compartment dissolved nutrients such as nitrates are uptake by the plants before the water return back to the fish tank.

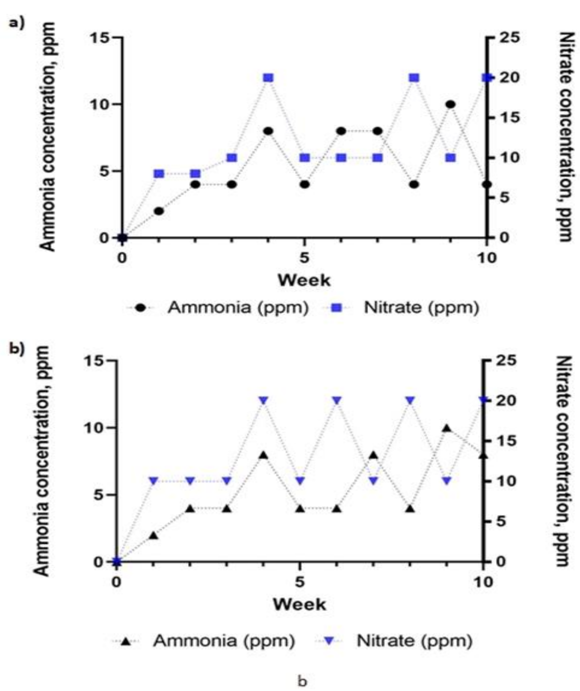


Figure 3 Weekly variation of ammonia (NH_3), and nitrate (NO_3^-) in the aquaponic system for the red tilapia and lettuce at two different flow rates; (a) Flow rate 1 (F1) of 50L/hr, (b) Flow rate 2 (F2) of 75L/hr. Water sample were taken from the fish tank once a week

Two different flowrates were applied; first, at flowrate of 50L/hr, and second at flowrates of 75 L/hr. In both operating conditions, in can be seen that there was a spike in the ammonia level for the first 2-3 weeks of the operation. However, ammonia levels in the fish tank drop to the range below 4 ppm from the fourth weeks onwards. Nitrate levels for both pump settings were between 5ppm and 30ppm, which is within the acceptable range for aquaponics operation. The spike of the ammonia level could be explained by two situations. First, nitrification bacteria community has not fully established in the whole system, and second, an increase in the uneaten fish food (fish feeding rates were also considered high i.e. nearly 20% of fish body weight). Water flowrate can assist in ammonia removal. that by setting the pump to operate at faster rates i.e. at 75 L/hr, the ammonia removal rates was faster and thus, justify the lower ammonia content (Figure 3b). Interestingly, it was also noticeable that the nitrates level for the slow operating rates (50L/hr) is lower (Figure 3a) compared to the other operating condition (Figure 3b). It seems that for a longer residence time, plants would have more time to consume the nitrates. Although a comparable trend of nitrogen cycle consumption was attained [15-17], the level of ammonia is a bit higher than the allowable threshold value (1 ppm) for aquaponics operation. It is assumed that if the number of bioballs and biorings in the filter tank are increased and by adding active nitrification bacteria solution into the recirculation line during the start-up of the operation, the level of ammonia could have been contained below 1 ppm.

Growth Performance of Plant and Fish

Figure 4 shows the growth profiles of red hybrid tilapia grown in the proposed aquaponics setup for the period of 10-weeks. The setup was operated at two different flow rates and growth of the fish is based on the average fish weight gain. Based on the results attained, in both flowrate settings, the average initial weight of fish (i.e. less than 5g) reaches a final average weight of around 50g, indicating a mean weight gain of around 358.7g for F1 (5L/hr) and 450.7g for F2 (75 L/hr) after 10 weeks of cultivation period. At the F1 operating conditions, it was seen that fish was growing rather slowly in the first 4-5 weeks. Only after the fifth week, fish growth was accelerating resulted in a partially sigmoid curve growth pattern. On the contrary, for the F2 settings, a rather steady growth was achieved through the period of 10-weeks. It is suspected that at faster pumping rates, a more comfortable living environment was created for the fish since ammonia removal from the fish tank is faster. This indeed accurate as the average ammonia concentration measured in F2 aquaponic setup did not spike more than 5 ppm compared to F1 aquaponic setup where the ammonia level rocketed up until 8 ppm in the first 3 weeks of the operation.
Moreover, the specific growth rate was 5.41% per day for F1 and 5.65% per day for F2. The total usage of fish feed in this 10-week study was around 1.7-2 kg. For F1,

the mean weight gain is 44.8g, this gives total growth of all eight fish of about 358.7g (44.8g x 8) with a food conversion ratio of 2.06. As for F2 condition, the mean weight gain is 51.4 g, this gives total growth of all eight fish of about 450.7g (51.4g x 8) with a food conversion ratio of 1.85. The FCR is merely an indicator on how much feed is required to develop one kilogram of fish. When FCR is low, the food feed to the fish is effectively consumed. Our data is comparable to what has been reported in the literature for stocking of small to moderate size fish during starting-up of fish cultivation in an aquaponics setup. Zainal Alam et al. [7] reported that smaller fish with weight around 20-25g will have a SGR value of around 7-8% per day and expected FCR value is somewhere between 1.7 and 2. It was also interesting to note that higher flow rate (F2) produces a better average fish weight gain of 450.7g with SGR of approximately 5.65%. This is probably because greater flow rates setting will provide better aeration and oxygen demand to the fish [18]. Moreover, our findings are consistent with larger aquaponics setup reported by Trang et al. (2017) [19]. Their system consisted of Tilapia tanks connected to a gravel filter and higher recirculation rates are needed to secure a good growth, sustain acceptable water quality for fish cultivation low FCR for the tilapia.

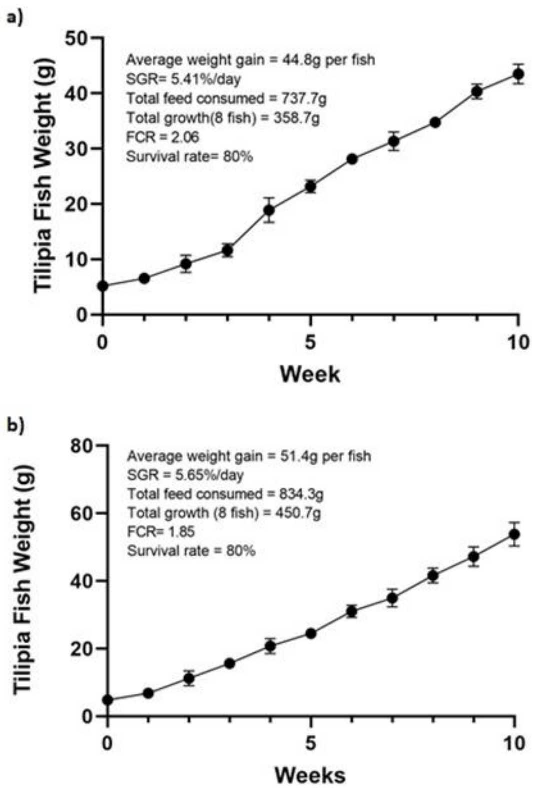


Figure 4 Tilapia fish weight gain over the period of 10-weeks cultivation at recirculation pumping rates of (a) F1=50L/hr and (b) 75L/hr. Inset shows the information pertaining to average weight gain, SGR, FCR and fish survival rate

Despite the difference in the recirculation pumping rates and average fish weight gain (p-value, 0.644 > 0.05), the survival rate of the fish for both flow rates settings was similar at 80%, where only 2 fishes were dying during the 10-week cultivation study. Causes of death could possibly due to fish stress (toxic environment and high ammonia content) and/or unexpected infection [20-21]. In this aquaponics setup, the stocking density is considered low with 8 fishes per cubic meter. Delaide, et al., [14] emphasize that removal of uneaten fish feed is essential to avoid overfeeding of fish which can lead to accumulation of excess ammonia content. These uneaten pellets may sink to the bottom of fish tank over time that can result in poor water quality of the fish tank.

The growth of green salad over the period of 10-weeks in our aquaponics setup is presented in Figure 5. Our results show that there is a significance difference on growth of the green salad in both pumping conditions (p-value, 0.667 > 0.05). For F1 settings (50L/hr), the plant grown at the rate of 1.5cm/week in the first five weeks before steadily grow to the height of about 18.7 cm. However, in F2 condition (75L/hr); the plant was growing at the rate of 2 cm/week but decelerated to a more steady growth reaching the height of about 19.1 cm. Despite the differences, it is clear that sufficient sunlight and nutrients supply for the plant growth have been provided throughout the 10-weeks cultivation period. The use of lightweight expanded clay aggregate (LECA) and sponges as the substrates in the net pot is also believed to have offered an excellent trait as media bed as well. It holds the roots of the plant in place whilst the air pockets between the loosely packed clay pebbles offered spaces for oxygenation of roots. Furthermore, capillary properties of LECA allowed water to travel several inches in upward direction to provide water to the plants for growth. Image of the green salad produced is presented in Figure 5. A bright green colour of the salad indicated that a healthy organic green salad has been produced.

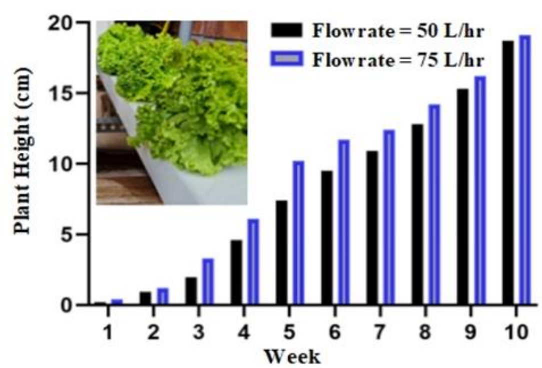


Figure 5. Growth profiles of the green coral lettuce based on the plant height over the period of 10-weeks. Inset shows the image of the green salad produced.

4.0 CONCLUSION

This research project outlines the development and construction of a compact aquaponics system that was conceptualized to function as a supplementary food source. The system's efficacy was tested by cultivating green coral lettuce and a red hybrid tilapia for a period of 10 weeks. The water circulation rate was manipulated to assess the effects of varying pumping rates on crop production yield and water quality. The findings indicated that increasing the water recirculation rate resulted in improved rates of ammonia removal, which was achieved by reducing the residence time in the fish tank. While there were minor differences in plant yield and fish growth, both crops were grown consistently. The specific growth rate (SGR) achieved was approximately 5.4-5.7%, with feed conversion ratio (FCR) of about 1.8-2. The fish survival rate was 80%, and the plant growth rate was approximately 1.5-2 cm/week. We believed that in future work, integrating technology such as sensors and automation to monitor and control the aquaponic system parameters effectively are essential. As this would help aquaponics practitioners better understand the principles behind successful system management.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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