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Research Paper

Optimum Stocking Density of *'koi'* Carp *(Cyprinus carpio)* in Combination with Different Plant Species in an Aquaponic System

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الكثافة المثلى لتربية أسماك الكوي كارب *(Cyprinus carpio)* مع نباتات مختلفة في نظام الإستزراع الأحيومائي

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Abstract. To maximize profits from aquaponic system, a high-price 'koi' carp *(Cyprinus carpio)* produced at Sultan Qaboos University was used. This study consisted of two experiments. The first experiment aimed to determine the optimal stocking density of 'koi' carp in an aquaponic system. In the second experiment, the optimal density of 'koi' carp based on the first experiment was used in combination with tomato, eggplant, and mint as a control from the first experiment. The aquaponic system consisted of 9 pairs of glass tanks; in each pair water was recirculating with the use of a submersible pump. In the first experiment, 'koi' carp fry (0.4-0.5 g each) were stocked at 50, 100 and 150 individuals per tank (0.1 m^3) in combination with mint and the ornamental plant *Petunia*. Fish were stocked in tanks with and without plants. Results show that 'koi' carp stocked at 100 per tank without plants had significantly better growth (mean final weight of 7.5 g from the initial weight of 0.4-0.5 g). Fish stocked in tanks with plants, 'koi' carp at 50 per tank had significantly better growth (mean final fish weight of 5.2 g from the initial weight of 0.4-0.5 g). Survival rate was highest at 50 per tank with or without plants. Mint growth was better in tanks with 50 fish per tank. *Petunia* had flowers in all treatments. Water quality parameters were within optimal range even at high fish stocking densities. Overall, stocking density of 50 fish per tank can be recommended based on survival data. In the second experiment, 30 'koi' carp juveniles were stocked in all tanks without plants (i.e. 6.5 g, 5.5 g and 6.1 g respectively) for each treatment in combination with mint, tomato, and eggplant. Growth and survival rates of koi (30 fish per tank) in combination with mint, eggplant and tomato were high with a weight gain of 21.3, 17.6, 17.6 g and survival rate of 90%, 95.5% and 87.8%, respectively. The results showed that 'koi' can be successfully grown with different plants in an aquaponic system.

Keywords: Aquaponics, Koi carp, *Cyprinus carpio*, eggplant, mint, *Petunia*

الملخص:تم استخدام أسماك الكوي كارب (Cyprinus carpio) عالي السعر والمنتج في جامعة السلطان قابوس من أجل تحقيق أقصى قدر من الأرباح من نظام الاستزراع النباتي والسمكي في هذه الدراسة، والتي تتكون من تجربتين: هدفت التجربة الأولى إلى تحديد الكثافة المثلى لتربية أسماك الكوي كارب في نظام الزراعة الأحيومائية. أما في التجربة الثانية فقد تم استخدام الكثافة المثلى لأسماك الكوي كارب بناءً على التجربة الأولى مع الطماطم والباذنجان والنعناع كعنصر تحكم من التجربة الأولى. يتكون نظام الزراعة الأحيومائية من ٩ أزواج من الخزانات الزجاجية، حيث يتم إعادة تدوير الماء في كل زوج بإستخدام مضخة غاطسة، ففي التجربة الأولى، تم تخزين زريعة أسماك الكوي كارب (٠,٤–٠,٥ جرام لكل منها) عند ٥٠ و ١٠٠ و ١٥٠ زريعة لكل خزان (٠,١ متر مكعب٣) مع النعناع ونبات الزينة البطونية. تم تربية الأسماك في خزانات مع وبدون نباتات، حيث أوضحت النتائج أن أسماك الكوي كارب المخزنة عند ١٠٠ زريعة لكل حوض بدون نبات كان لها نمو أفضل (متوسط الوزن النهائي ٧,٥ جرام من الوزن الأولي ٠,٤–٠,٥ جرام). وقد تمتعت الأسماك التي تم تربيتها في أحواض مع النباتات بمعدل ٥٠ زريعة لكل خزان بنمو أفضل (متوسط الوزن النهائي للأسماك البالغ ٥,٢ جرام من الوزن الأولي البالغ ٠,٤–٠,٥ جرام)، وكان معدل البقاء على قيد الحياة أعلى في الخزانات التي تحتوي على ٥٠ سمكة مع أو بدون نباتات، وكان نمو النعناع أفضل في الخزانات مع ٥٠ سمكة لكل حوض، وقد لوحظ أن البطونية كانت مزهرة في جميع التجارب، وكانت معايير جودة المياه ضمن النطاق الأمثل حتى عند الكثافة العالية لتخزين الأسماك. يمكن التوصية بشكل عام بتربية الأسماك البالغة في كثافة مقدارها ٥٠ سمكة لكل حوض بناءً على بيانات البقاء على قيد الحياة. في التجربة الثانية، تم وضع ٣٠ من صغار أسماك الكوي كارب في جميع الأحواض الخالية من النباتات (أي ٦,٥ جرام ، ٥,٥ جرام ، ٦,١ جرام على التوالي) لكل تجربة مع النعناع والطماطم والباذنجان، ولوحظ أن معدلات نمو وبقاء أسماك الكوي كارب (٣٠ سمكة لكل حوض) مع النعناع والباذنجان والطماطم كانت عالية مع زيادة في الوزن بلغت ٢١,٣ و ١٧,٦ و ١٧,٦ جرام ومعدل بقاء ٩٠٪ و ٩٥,٥٪ و ٨٧,٨٪ على التوالي، وكخلاصة فقد أظهرت النتائج أنه يمكن زراعة الكوي كارب بنجاح باستخدام نباتات مختلفة في نظام تربية الأحياء المائية.

الكلمات المفتاحية: الزراعة الأحيومائية، كوي كارب، باذنجان، نعناع، البطونية.

Introduction

In response to an increase of human population and the various challenging issues of climate change, soil corruption, decrease in fish population, increase in utilization of natural resources such as water and soil, and water scarcity (Merino et al., 2012) there is a need to develop and utilize production systems that are environment-friendly. One production system is aquaponics which is a closed-loop system that combines aquaculture and hydroponics without the use of the soil (Hussain et al., 2016). Aquaponics work on the principle of the nitrogen cycle, wherein dissolved waste created from the production system is successfully changed over to plant nutrients by advantageous nitrifying bacteria. It

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converts ammonia released from fish and residual feed to nitrate to be used by the plants for their growth. Recycling aquaculture systems already produce large volumes of fish in a small footprint without aquaponics. It also allows for expanded generation utilizing a similar volume of water and nutrient input. By this technique, it is possible to reduce wastes and related natural effects, and in the meantime produce fish and plant crops as well as increase financial income (Schmautz et al., 2017). Due to the global drop in oil prices and the lack of job opportunities, the government of the Sultanate of Oman headed to strengthen its sustainable wealth, such as agriculture and fisheries sector. The Sultanate of Oman is considered one of the areas with scarcity of water, thus, aquaponics is an ideal solution to enhance the economy of the country and providing job opportunities along with reducing water consumption.

Currently, the government, represented by the Ministry of Agriculture and Fisheries, is working to provide support for many projects in this field.

'Koi' carp (*Cyprinus carpio*) is an ornamental fish with high market demand because of its color patterns. It has great demand in South East Asian countries, and being hardy in nature, it is highly suitable for garden pools and aquariums. Limited information on 'koi' carp culture in aquaponics system is available (Hussain et al., 2016). The main objectives of this experiment were to determine the optimal density of 'koi' carp (*Cyprinus carpio*) stocked in tanks with and without plants (mint and *Petunia*) in aquaponic system, to determine the feasibility of growing 'koi' carp and plants in one tank to maximize space. It also aimed to optimize the growth of 'koi' carp stocked with different plants (i.e. mint, eggplant, and tomato).

Materials and Methods

Eighteen (18) units of glass tanks (80×40×40 cm) containing 100-liter of tap water were set up in pairs. All tanks were identical allowing replication of experimental treatments. Nine of the 18 tanks were without plants the other 9 tanks were with plants. The fish tanks without plants were placed on a platform while the fish tanks with plants were placed on the floor. All tanks were connected with air stones to provide dissolved oxygen to the fish and plants. Each fish tank without plants was connected to fish tank with plants with a pipe or hose to allow water to flow by gravity from the fish tank without plants to the fish tanks with plants. The fish tanks with plants had gravels on the bottom and a vertical layer of gravels in net bags on one end of the tank before the submersible pump to filter the water from solid wastes and bring the filtered water back to the fish tank without plants. Each tank had a 3-cm thick Styrofoam covering the entire water surface. For fish tanks without plants there was a small opening for the feed to be given. For fish tanks with plants, each Styrofoam cover (i.e. polyethylene raft) had 13 -15 evenly-spaced holes for the plants as shown in Figure 1.

Experiment 1

All 18 tanks were used to grow 'koi' carp (*Cyprinus carpio*) with an average of initial weights of 0.4-0.5 g each stocked at 50, 100, 150 fish per tank (i.e. 0.1 m^3). The lower 9 tanks were planted with mint and *Petunia* in each tank. Both plants were cut (i.e. 10 cm long) and wrapped around with cotton on the lower part and placed in a plastic seedling container with open bottom to allow the roots to go down into the water. The experiment was conducted for 91 days.

Experiment 2

The upper 9 units were used to grow 'koi' carps of the initial weight of 6.5 g, 5.5 g and 6.1 g for each treatment at the same stoking density of 30 juvenile per tank. The lower 9 tanks were used to grow mint, eggplant and tomato in each tank. The same growing method was used as in the first experiment. The experiment was conducted for 56 days.

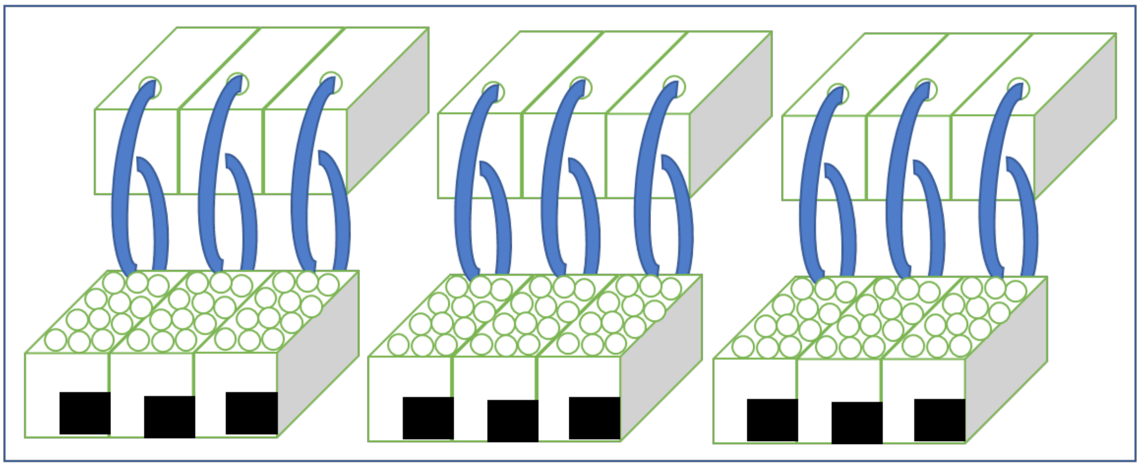

Figure 1. The aquaponics system; upper tanks had fish only, lower tanks had fish and plants

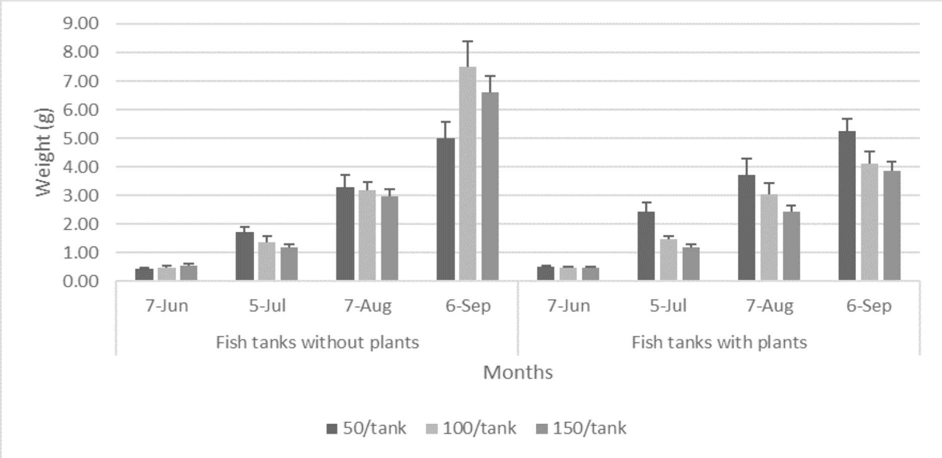

Figure 2. Growth (average weight and standard error of mean) of fish in tanks with and without plants.

Fish, Plants and Water Sampling

Every week, pH, dissolved oxygen (DO, mg/L) and temperature (°C) were measured. Fish weights were measured every month. Samples of 10, 20, 30 fish were weighed from treatments 1, 2, 3 from both fish tanks without plants (upper tanks) and fish tanks with plants (lower tanks) in the first experiment, and 30 fish from each tank were measured in the second experiment. The length of 10 mint plants from each tank were measured, and the number of flowers of 10 *Petunia* were counted in the first experiment and the length of all plants were measured in the second experiment.

Data Analysis

All collected data such as weights of fish and lengths of mint branches were plotted in Microsoft Excel Program. Average and standard error of mean were calculated and the graphs were plotted. ANOVA was calculated for weight of fish and height of mint followed by Tukey's test for significant difference at $P<0.05$.

Results

Experiment 1

Growth of Fish: In the fish tanks without plants, the final weights of fish in treatment 1 (50 fish/tank), treatment 2 (100 fish/tank) and treatment 3 (150 fish/tank) were 5.0 g, 7.5 g and 6.6 g from the initial weight of 0.42 g, 0.48 g and 0.52 g, respectively (Figure 2), corresponding to weight gain of 4.5, 7.02, and 6.08 g, respectively, in 90 days. There were significant differences in growth of fish at different stocking densities (P-value = 0.04). There were significant different between treatment 1 and 2 (P-value = 0.04), however " there were no significant different between treatment 1 and 3 (P-value = 0.19) and 2 and 3 (P-value = 0.57) ". In tanks with plants, the final weights of fish in treatment 1 (50 fish/tank), treatment 2 (100 fish/tank), treatment 3 (150 fish/tank) were 5.2 g, 4.1 g, 3.8 g from the initial weight of 0.51 g, 0.47 g and 0.47 g respectively (Figure 2). Final weight at 50 per tank

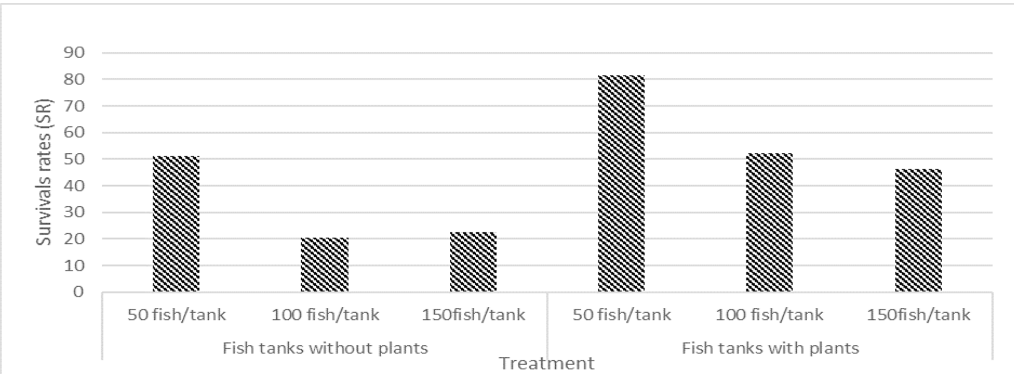

Figure 3. Survival rate of fish in fish tanks without and with plants, after 91 days.

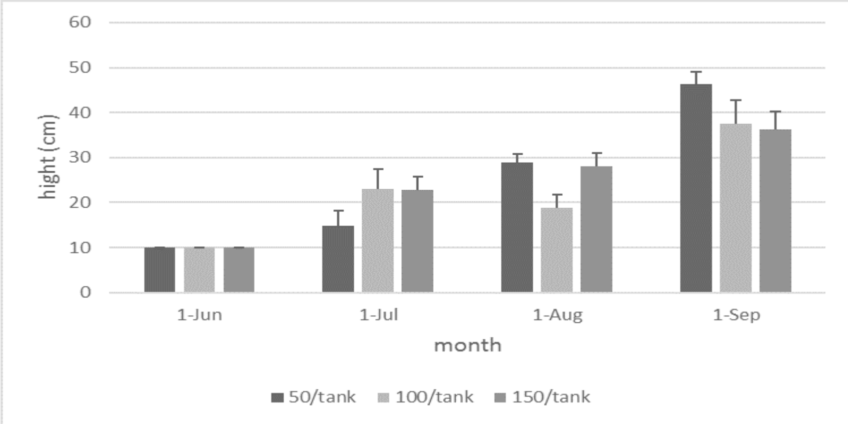

Figure 4. Growth (average length and standard error of mean) of mint plants.

was significantly different from those at 100 and 150 per tank (P-value = 0.04). There were significant different between treatment 1 and 3 (P-value = 0.04), however " there were no significant different between treatment 1 and 2 (P-value = 0.09) and 2 and 3 (P-value = 0.90) ".

Survival Rate: The average survival rate of fish in treatment 1 (50 fish/tank), treatment 2 (100 fish/tank), treatment 3 (150 fish/tank) was 51.3%, 20.7% and 22.7% respectively in fish tanks without plants and 81.3%, 52.3% and 46.2% in fish tanks with plants from the initial number of fish 50, 100 and 150 (Figure 3).

The initial number of Petunia flowers in treatment 1 (50 fish/tank), treatment 2 (100 fish/tank), treatment 3 (150 fish/tank) was 14, 14, 18 respectively (Figure 5) and the final number of *Petunia* flowers in treatment 1 (50 fish/tank), treatment 2 (100 fish/tank), treatment 3 (150 fish/tank) was 19, 23, 20, respectively (Figure 5).

Water quality

Dissolved oxygen: The dissolved oxygen (DO) in the fish and plant tanks was fluctuating. It ranged from 3.49 to 8.16 mg/l. DO was highest in treatment 1 (50 fish/tank),

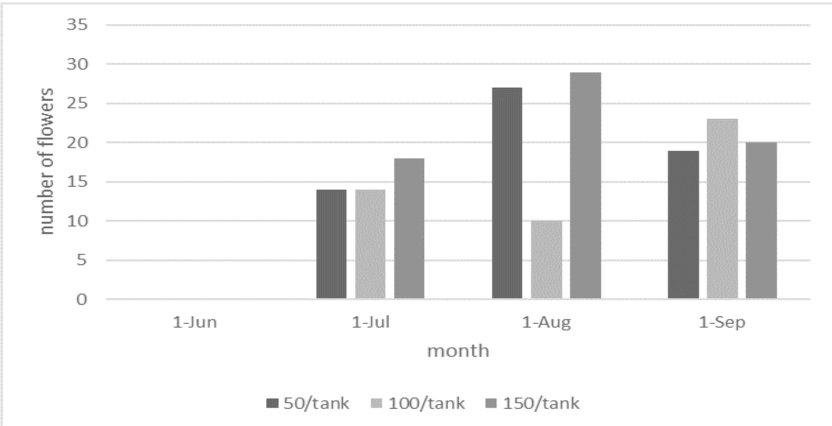

Figure 5. Number of flowers produced by Petunia plants in the aquaponics system with different fish densities.

Growth of plants: The average final lengths of mint in treatment 1 (50 fish/tank), treatment 2 (100 fish/tank), treatment 3 (150 fish/tank) was 46.3 cm, 37.5 cm and 36.3 cm, respectively from the initial length of 10 cm (Figure 4). However, there was no significant difference in growth of mint at different fish stocking densities (P-value = 0.17).

whereas, the lowest DO concentration was in treatment 3 (150 fish/tank) (Figure 6 and 7).

Temperature: The temperature in the fish and plant tanks was fluctuating. It ranged from 29.73 to 36.17°C (Figure 8 and 9), decreasing towards the end of summer when the experiment ended.

pH: The pH in the fish and plant tanks was fluctuating but within optimal range. It ranged from 6.72 to 7.82. pH was highest in treatment 1 (50 fish/tank), whereas, the lowest pH concentration was in treatment 2 (100 fish/tank) (Figures 10 and 11).

Survival Rate: The average survival rate of fish in treatment 1 (fish with mint), treatment 2 (fish with eggplant), treatment 3 (fish with tomato) was 90%, 95.5% and 87.8% respectively from the initial number of 30 fish (Figure 14).

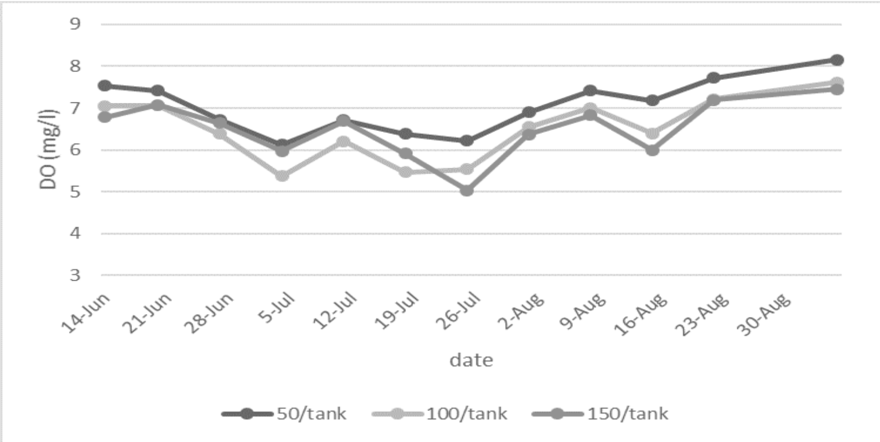

Figure 6. Dissolved oxygen (DO) in fish tanks without plants.

Experiment 2

Growth of Fish: *Fish Weight*: The final weights of fish in treatment 1 (fish with mint), treatment 2 (fish with eggplant) and treatment 3 (fish with tomato) was 27.8 g, 23.1 g and 23.7 g from the initial weight of 6.5 g, 5.5 g and 6.1 g, respectively (Figure 12), corresponding to weight gain of 21.3, 17.6 and 17.6 g, respectively. There were no significant differences in growth of fish in combination with different plants (P-value = 0.12).

Fish Length: The final lengths of fish in treatment 1 (fish with mint), treatment 2 (fish with eggplant) and treatment 3 (fish with tomato) was 11.1 g, 10.7 g and 10.5 g from the initial weight of 5.5 g, 5.0 g and 5.7 g, respectively (Figure 13). There were no significant differences in growth of fish at different plants (P-value = 0.26).

Growth of Plant: The average final length of mint was 39.5 cm from the initial length of 10 cm, eggplant was 47.4 cm from the initial length of 41.7 cm and tomato was 28.4 cm from the initial length of 1.6 cm (Figure 15). For the tomato plants, white spots were observed in the upper surfaces of the leaves that appear to be *Oidium* disease (Kiss et al., 2001)

Water quality

Dissolved oxygen: The dissolved oxygen (DO) in all treatment was fluctuating. It ranged from 3.49 to 8.16 mg/l. DO was highest in treatment 1 (fish with mint), whereas, the lowest DO concentration was in treatment 3 (fish with tomato) (Figure 16).

Figure 7. Dissolved oxygen (DO) in fish tanks with plants.

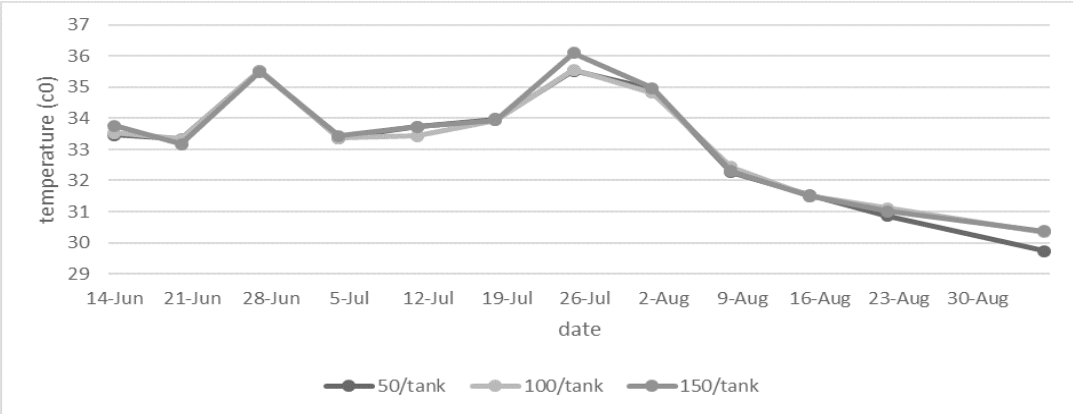

Figure 8. Temperature in fish tanks without plants.

Temperature: The temperature in the fish and plant tanks was fluctuating. It ranged from 20.70 to 31.07°C (Figure 17), decreasing towards the start of winter when the experiment ended.

pH: The pH in the fish and plant tanks was fluctuating but within optimal range. It ranged from 6.38 to 7.29 (Figure 18).

Nutrients: Figure 19 shows concentrations of phosphate, nitrate and sulphate in each treatment per sampling month. The nitrate concentration was highest in the last month (23-Nov). It also shows higher rate of increase in the treatment with mint and a steady increase in the treatment with eggplant. The phosphate concentration was highest in 7-Aug for both treatments with mints and eggplants, and highest in 5-Jul in the treatment with tomatoes. Phosphate concentration tend to decrease in 23-Nov for the treatments of mint and eggplant where it shows some increase in the treatment with tomatoes. Sulphate concentration was high in the treatment with eggplant, and shows some fluctuation for both treatments of eggplant and tomato. It also shows some steady increase in the treatment with mint.

Figure 20 shows the concentrations of potassium, calcium magnesium and sodium in each treatment per sampling month. There was an increase in potassium in the treatment with mint, while it was fluctuating in treatments with eggplant and tomato. The calcium concentration increased in the last month for all the treatments, where it reached almost the same concentration. There was an increase in magnesium in all treatments, where the concentration was almost the same in the last month. On 7-Aug, the concentration of magnesium in the treatment with tomatoes showed some decrease, while it continued to increase in the other treatments. There was a small increase in the concentration of sodium in all treatments with small decrease in the last month in the treatment with eggplant. The figure also shows sodium concentration was highest in the treatment with eggplant.

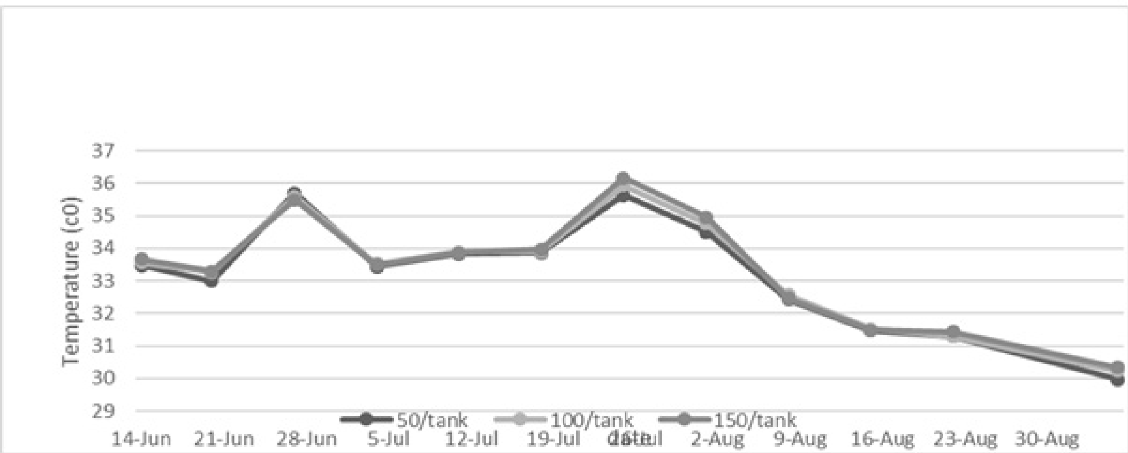

Figure 9. Temperature in fish tanks with plants.

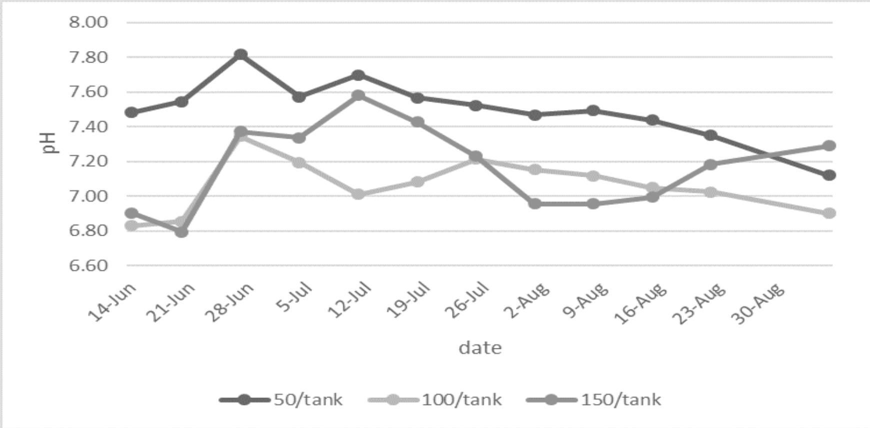

Figure 10. pH in fish tanks without plants.

Discussion

Experiment 1

Fish Growth at Different Stocking Densities With or Without Plants: Stocking density of fish is regarded as one of the most sensitive factors affecting growth rate, size variation and mortality determining productivity of a culture system (Hussain et al., 2016). Prithwiraj et al. (2008) reported an inverse relationship between stocking density and individual size of koi carp (*Cyprinus carpio*) in concrete tanks, primarily due to the shared food among individuals. In our experiment we aimed to determine the optimal stocking density for the aquaponic system. As we stocked the 'koi' carp at different densities (50, 100, and 150 fish/tank) and different state of environment (fish tanks without plants and fish tanks with plants), the data indicate that fish had different growth rates. Fish growth was higher in fish tanks without plants and this may be due to the tank volume. The plant tanks had gravels on the bottom and vertical layer of gravels in net bags on one end of the tank which reduces the living space of fish. In the three months of sampling of fish in tanks with or without plants and fish with plants, the increase in the fish weight was almost 0.5 g, whereas the increase of the weight between the third and the last samplings was higher by 1.73, 4.30 and 3.64 g, respectively in the fish tanks without plants, and 1.53, 1.08 and 1.42 g, respectively in the fish tanks with plants. According to Knaus and Palm (2017), the optimal temperature for *Cyprinus carpio* is between 25 and 30°C, which is suggested to be the reason of the increase for the fish weight at the last month.

Effect of Stocking Density on Growth of 'koi' Carp: Our hypothesis was that there will be a negative relationship between stocking density and fish growth, since increase in the stocking density will normally decrease the growth of fish. This study confirms our hypothesis as the results show that fish growth in the fish tanks without plants was significantly higher in treatment

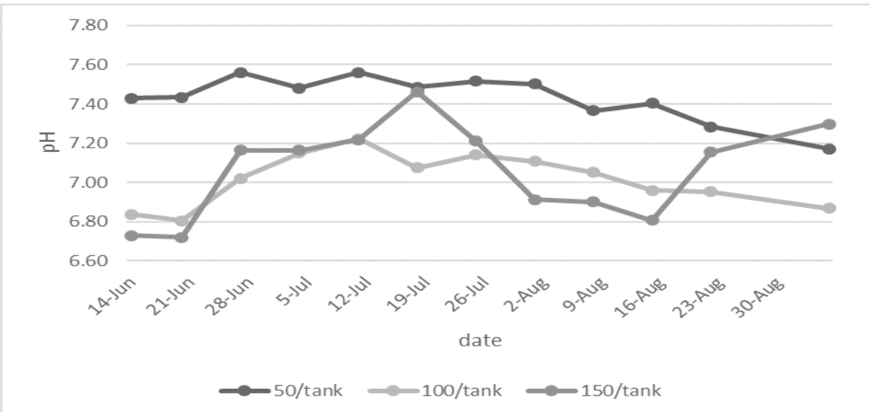

Figure 11. pH in fish tanks with plants.

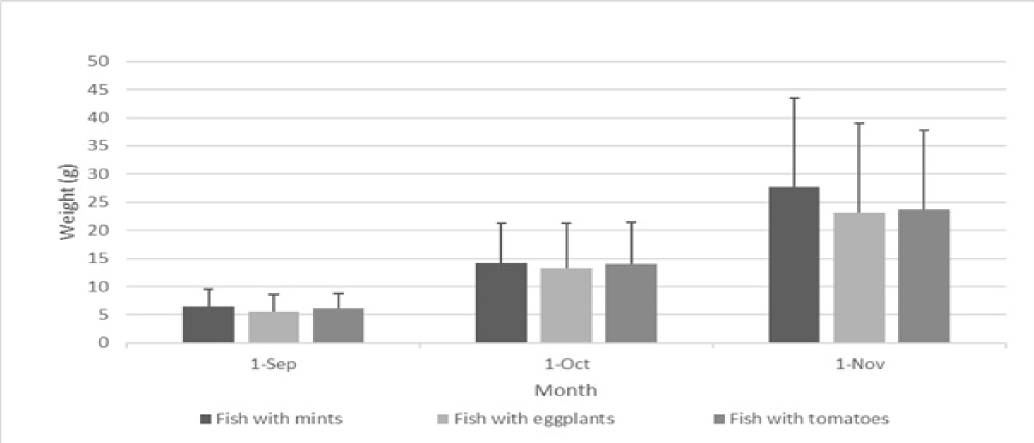

Figure 12. Weight (mean and standard deviation) of fish in combination with different plants.

1 (50 fish/tank) from first sampling to third sampling (i.e. 0.42±0.05 g, 1.71±0.20 g, 3.27±0.46 g). While in the last sampling the growth rate in treatment 2 (i.e. 100 fish/tank) "increased which may due to the death of fish in this experiment resulting in reduced density and thus an increase in the fish weight". However, in the fish tanks with plants, the fish growth was significantly higher in treatment 1 (i.e. 5.24±0.45 g) followed by treatment 2 (i.e. 4.12±0.43 g). The lowest growth in fish was observed in treatment 3 (i.e. 3.85±0.33 g). According to Karakatsouli et al. (2010), fish density can be affected by the light intensity inside the fish tanks, which affects fish behavior, stress, and growing performance. Moreover, it has been found that some species including 'koi' carp culture can be highly sensitive to nitrogen toxicants, where depression of feeding can be one of the common problems if the water quality is sub-standard and the higher density can results in higher nitrogen toxicants in the tank (Prithwiraj et al., 2008). The reduction of space availability for fish, can increase aggressive behavior and food competition, which can in turn cause stressful conditions, decrease survival rate (Jha, et al, 2008) and reduce growth rate (Nuwansi et al., 2021). Survival rate of the fish during the experiment were significantly higher in treatments 1 for both fish tanks without plants and fish tanks with plants (51.3% and 81.3% respectively). During the first months of experiment, the number of dead fish increased especially in the treatment 2 and 3. According to Jha et al. (2007), 'koi' carp can adapt to fluctuating and extreme temperature but if the temperatures increase beyond the thermal limit the mortality will increase too. The maximum critical temperature of 'koi' carp is 35ºC where the minimum critical temperature is 15ºC (Zutshi et al., 2020).

Plant Growth: The length of mint in all treatments at the end of experiment did not show any significant difference ($p \geq 0.05$). According to Knaus and Palm (2017), the optimal water temperature in aquaponics system for

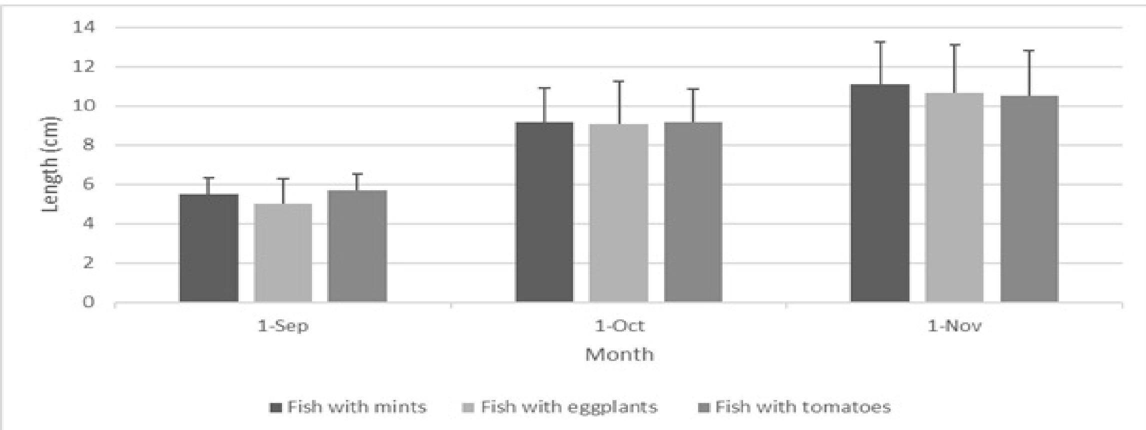

Figure 13. Length (mean and standard deviation) of fish in combination with different plants.

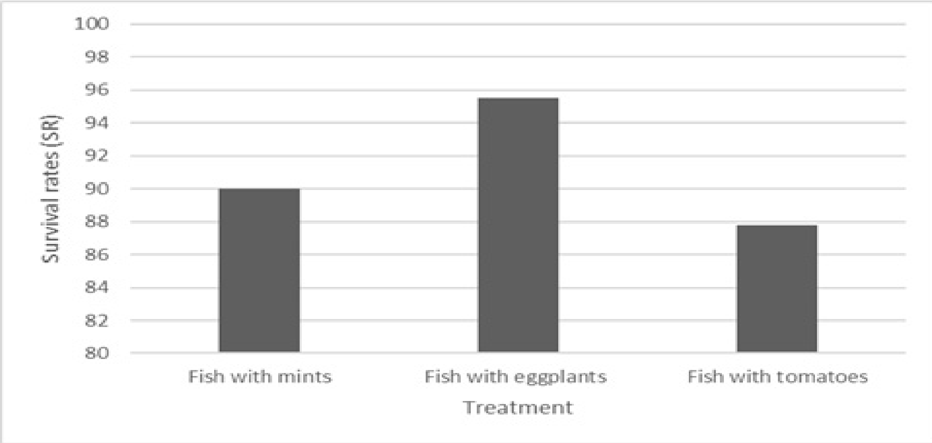

Figure 14. Survival rate of fish, after 56 days.

plant production between 22 and 24 °C. In this study, the number of Petunia flower increased during the first 3 sampling and that may be due to temperature decreasing and started to decrease in the last sampling due to decrease in pH.

Physico-chemical Water Parameters: Water quality factors (temperature, pH, dissolved oxygen) changed during the experiment. The temperature was fluctuating, ranging from 29.73 to 36.17°C. At the beginning it was high during summer and then it decreased due to the start of fall season. The dissolved oxygen was high in all the treatment at the beginning of experiment due to clean tanks. Later on it started to decrease due to the increased production of wastes which were acted upon by decomposing bacteria that also consumed the oxygen. Treatment 1 in both fish tanks without plants and fish tanks with plants had high DO due to lower density of fish in this treatment. According to Shete et al. (2017), in aquaponics system the optimal level of pH of the water for the process of nitrification, survival and growth of fish and plants is 7. In this study, we indicate that the pH in treatment 1 in both fish tanks without plants and fish tanks with plants were in the range of 7.17-7.43 and 7.12-7.48, respectively) which is favorable for the growth of fish and plant.

Experiment 2

Effects of the Plants on Fish Growth and Survival: As the results show, the treatment where the fish gained more weight was the one with mint (mean initial weight 6.5 g, mean final weight 27.8 g), whereas both treatments of the eggplant and tomato were almost the same (i.e. mean initial weight 5.5, 6.1, and mean final weight 23.1, 23.7 g, respectively) and this is also true for the fish length (i.e. mean final length of 11.1, 10.7, 10.5 cm, respectively). The survival rate was best in the second treatment where eggplants were planted followed by mint and then tomato. From the results, the treatment where the 'koi' carp have gained more weight and length and has the best growth rate was the treatment with the mint.

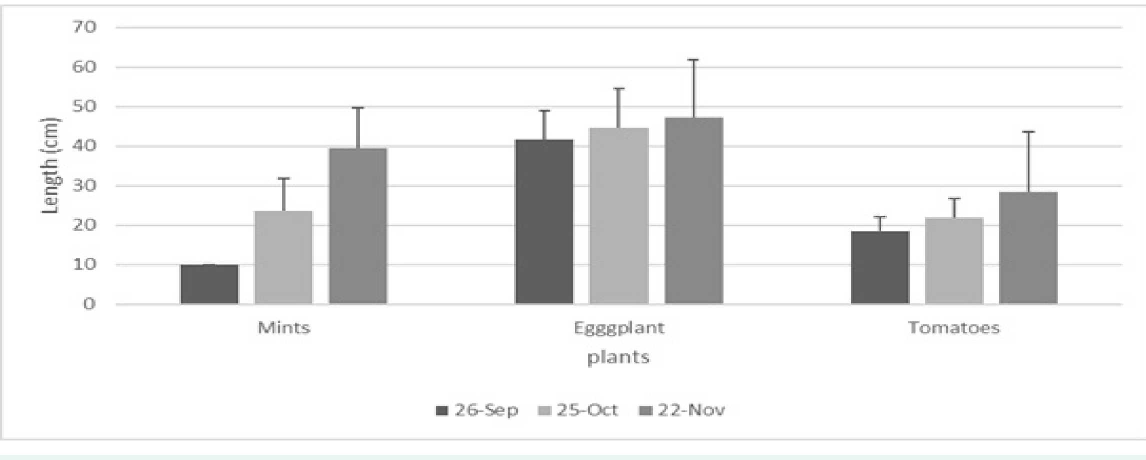

Figure 15. Growth (average length and standard deviation) of plants.

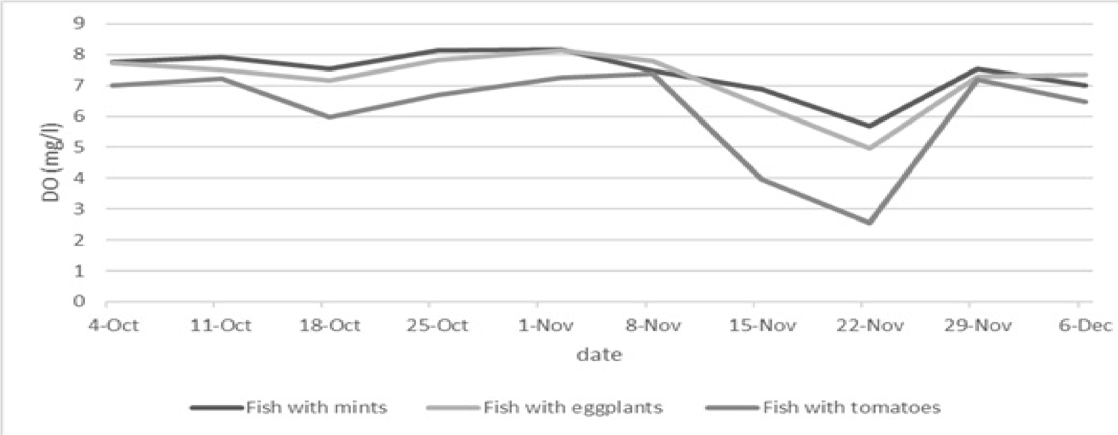

Figure 16. Dissolved oxygen (DO) in fish tanks with different plants.

Plants Growth: Mint grew faster than eggplant and tomato because mint is a low-nutrient-demand plant whereas eggplant and tomato are high-nutrient-demand plants because they are fruiting plants (Somerville et al., 2014). Growth of eggplant was slower but it started to produce flowers and fruits at the end of the experiment. The increase of plans growth and flower production was due to the increase of nutrients supplied by the fish, where higher stocking density of fish results in higher nutrients supplied and higher plant growth (Nuwansi et al., 2021). The nutrients from fish tank wastewater provide better environments for plant growth and produce higher yields than soil grown yields (Nuwansi et al., 2021). In the last month, the tomato plants started to have white spots like a powder on their stems and the upper surfaces of the leaves. According to Kiss et al. (2001), these white spots are caused by powdery mildew fungi *Oidium spp* that can be avoided by providing the best conditions for tomato plants to grow and supplying a sufficient amount of potassium.

Physico-chemical Water Parameters: Fish health, welfare, and plant requirements of the plants are directly affected by water quality parameters (Nuwansi et al., 2021). Both the dissolved oxygen and the temperature were fluctuating during the months of experiment. The dissolved oxygen was higher in the first treatment with the mint (8.16 mg/l) and it reached lowest in the third treatment with the tomato where it reached 3.49 mg/l and this may be due to the higher demand of tomato roots for oxygen. The temperature ranged between 20.7oC and 31.07°C. The range of pH was optimal during the months of experiment where it was between 6.38 and 7.29.

Nutrients: For the treatments with the mint, the concentrations of nitrate, sulfate, sodium, potassium, calcium, and magnesium were increasing during the three months, whereas the phosphate concentration decreased in the third month of sampling. The nitrate, calcium, and magnesium concentrations were increasing for the treatment with eggplant while the other nutrients showed some decrease in the third month.

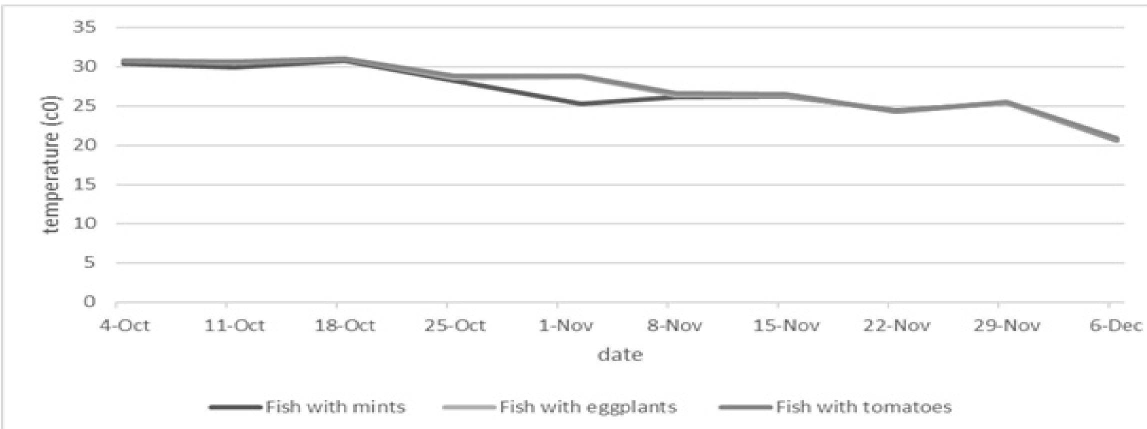

Figure 17. Temperature in fish tanks with different plants.

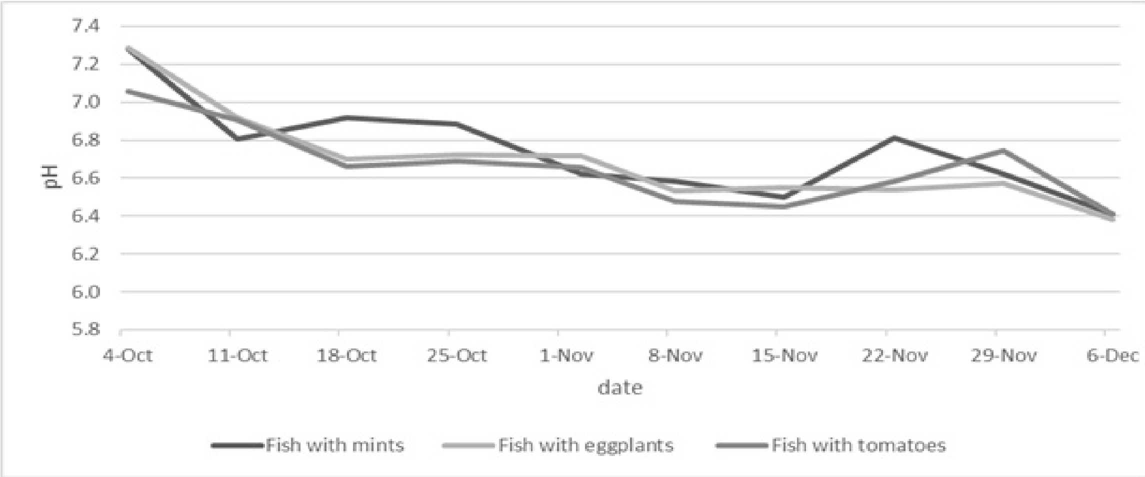

Figure 18. pH in fish tanks with different plants.

Finally, the concentrations of nitrate, sodium, and potassium increased for the treatment with tomatoes, while phosphate showed some decrease in the concentration during the three months. The other micronutrients showed some decrease in the second month and increase in the third month of sampling. The decrease in the second month could be due to the increased uptake of the plants while the increase in the third month could be due to the accumulation of nutrients from the feeds. In the case of nitrates, the increase could be due to the increased conversion of ammonia to nitrite and then to nitrate by the nitrifying bacteria (Somerville et al, 2014). Although some of the nutrients can be toxic to the fish like nitrate, it is the most important nutrient that

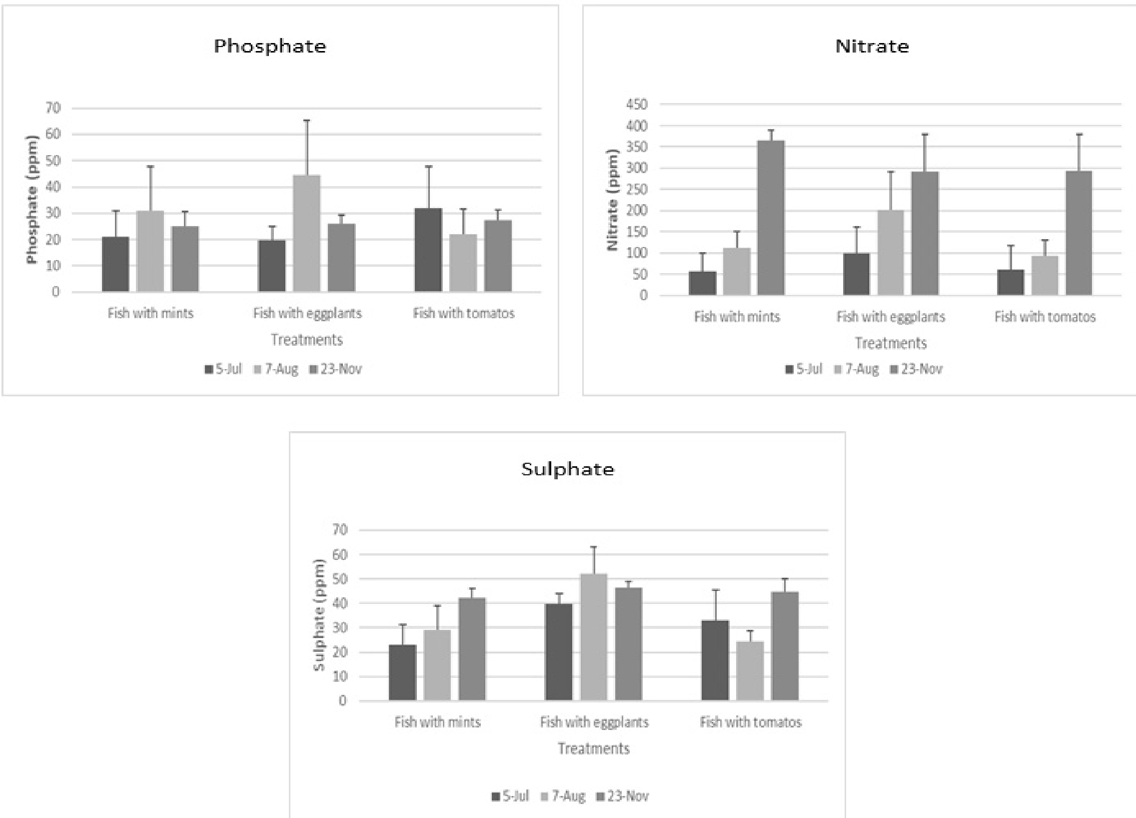

Figure 19. Concentrations of phosphate, nitrate and sulphate in fish tanks with different plants.

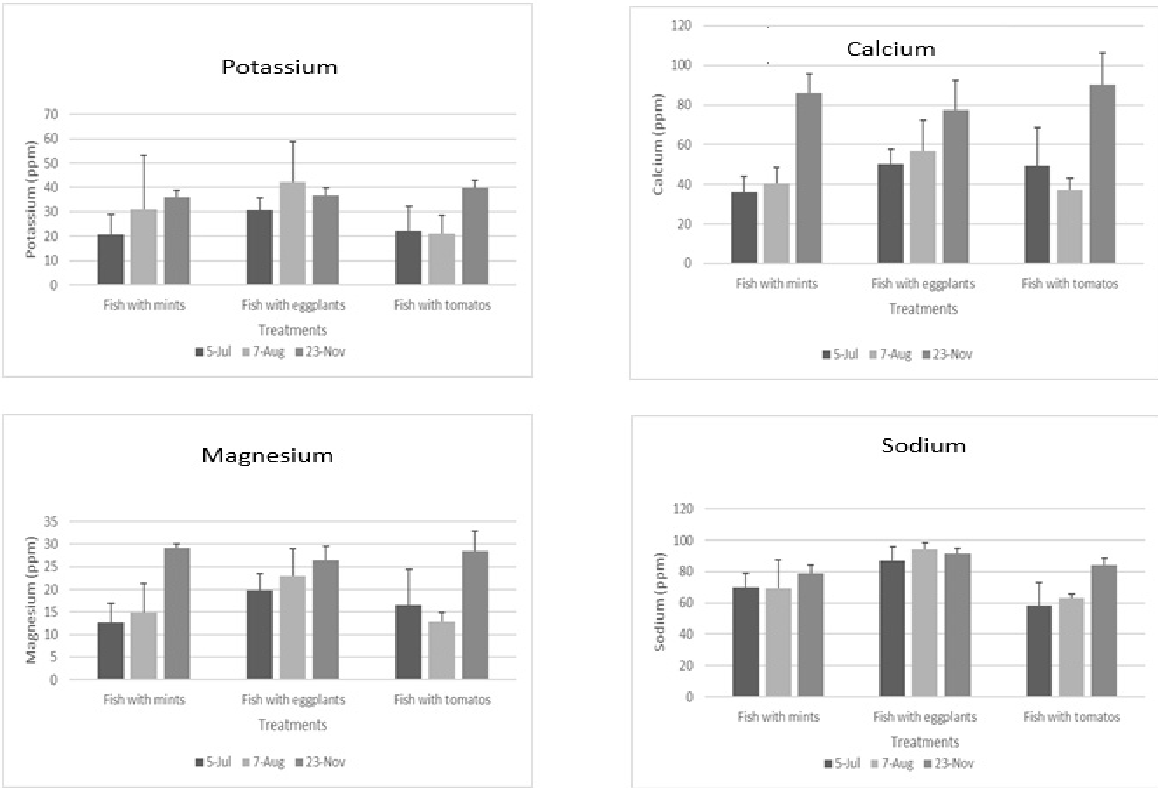

Figure 20. Concentrations of potassium, calcium, magnesium and sodium in fish tanks with different plants.

can enhance plants productivity (Nuwansi et al., 2021).

Conclusion

In the first experiment using 'koi' fry with initial weight of 0.4-0.5 g stocked at 50, 100 and 150 fry per tank (i.e. 0.1 m^3) with or without plants, the stocking density of 50 fish per tank with plants is considered the optimal density for 'koi' carp growth. Mint grew better in combination with fish at 50 per tank while the number of *Petunia* flowers varied. Water quality was better at lower fish stocking density. In the second experiment using 'koi' juveniles with average initial body weight of 6 g stocked at 30 fish per tank, mint grew best compared to eggplant and tomato. Growth and survival rates of 'koi' in combination with mint, eggplant and tomato were high. This research indicates that 'koi' carp can be successfully grown in combination with mint, Petunia, eggplant and tomato in an aquaponic system.

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