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Research Article

A pilot study on the lettuce and cucumber mixed cultivation in a recirculated aquaponics system

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ABSTRACT

Lettuce and cucumber are two essential salad ingredients that must be included for the dish to be complete. In the current study, we carried out a small pilot study on the co-cultivation of lettuce and cucumber in an effective aquaponics system. The experiment lasts for a total of four months, during which time the lettuce and cucumbers are grown for three and four months, respectively. In between the lettuce plants, which were grown at a density of 17 plants per square meter, the cucumber plants were planted at a density of 3 plants per square meter. Each month, the physicochemical quality and yield performance of harvested lettuce and cucumbers were evaluated. In the mixed cultivation method, lettuce and cucumber produce more, and the biochemical reports reveal no significant change over the course of the entire experimental period. The third month of lettuce production revealed a significantly lower overall yield. The final results showed that both crops were successfully utilizing the nutrients in the aquaponics water, demonstrating the efficiency of the nitrification process in the aquaponics environment. According to the findings, the current experiment suggests cucumber and lettuce be grown together, which is suitable for aquaponics systems. The study also found that cucumber and lettuce can be grown together in an aquaponic system without any negative effects on either crop.

INTRODUCTION

By combining hydroponics and aquaculture, aquaponics creates a special system that can reduce waste and increase food production per unit of area. Hydroponics is the practice of growing plants in water-run systems without using soil or other substrates at all [1]. Fish and other living things are raised for human consumption through aquaculture in watery areas. When the fish first started eating the food in the tank, they naturally emitted ammonia as fertilizer. After that, bacteria transform the ammonia into the form that plants can use, nitrate, before returning it to the tank [2,3].

Recirculation aquaponics (RAS) is a water recirculating system that can produce fish and plants. It offers controlled conditions, improved water quality, reduced usage, waste management, and nutrient recycling. Fish waste and microbial breakdown of feed are absorbed by plants, allowing for faster growth and higher production. RAS techniques are highly efficient, utilizing fish waste as nutrients for plants, creating a symbiotic environment for both fish and plants [4-6].

The wise use of water in agriculture is crucial for achieving good earnings and minimizing water use conflicts in arid and semi-arid countries. The benefits of integrating agriculture and fish culture include improved fishpond water quality [7], decreased environmental impact from nutrient-rich water discharge into receiving streams [8] and decreased water costs and crop fertilizer requirements [9]. Aquaculture and agriculture can be integrated to produce increased production because the same water can be used to grow two different crops. Utilizing two or more production systems, integrated farms maximize profits [10].

Lettuce, for example, is a great candidate for cultivation in an aquaponics system due to its low to medium nutrient requirements, rapid harvest period, and pest resistance (in comparison to fruiting plants; [11, 12]. Contemporary aquaponics, which mixes aquaculture and hydroponics, is a promising resource for long-term sustainability [13]. Plants in the system get their organic food and nutrients from the fish waste, and the fish in turn benefit from the water that has been cleaned, filtered, and recycled by the plants. These methods were initially developed for use with lettuce [14] but were quickly adapted for use with tomatoes [15] and other plants [16]. These include water spinach [17], spinach [18], lettuce [19 -21], tomato [22], cucumber [23-25], and pepper [26].

Lettuce contains several essential minerals for human health, including iron, zinc, calcium, phosphorus, magnesium, manganese, and potassium, as well as other bioactive compounds that promote health (Kim et al., 2016). Also, it contains β- carotene and fatty acid, have been found in high concentrations in crisp head, butterhead, romaine, green and red leaf lettuces [27, 28, & 29]. The cucumber (*Cucumis sativus* L.) is a significant vegetable crop native to south Asia, specifically the warm, humid climate of the Himalaya in Northwest India and potentially northern Africa. On a large scale, pickles, pahari rayata, and brining are all made from the immature fruit of the cucumber [30]. The fruit provides good amounts of salt, magnesium, potassium, sulphur, silicon, fluorides, and other nutrients. Its water content is between 93 and 95%. In addition, cucumber is a good provider of folate, potassium, calcium, and magnesium [31]. Cucumber yield and nutritional parameters in the aquaponics and hydroponics system were thoroughly analysed and published [32].

In the present study, cucumber (Cucumis sativus L.) and lettuce (*Lactuca sativa*) were carefully nurtured within the confines of a greenhouse aquaponics system with the objective of assessing their growth efficiency, biochemical composition, and yield quality. This study aims to identify the effect of mixed cultivation on yield efficiency. This study aimed to unravel the intricacies of cultivating lettuce in this unique environment and explore its potential benefits. By analyzing various parameters such as nutrient uptake, photosynthetic activity, and plant development, we sought to gain insights into the effectiveness of this innovative approach. The results of our study provided valuable insights into the effectiveness of utilizing greenhouse aquaponics systems for Cucumber and lettuce mixed cultivation.

MATERIALS AND METHODS

System description

The well-designed RAS (Recirculated Aquaponics System) was used for this experiment and the system volume description is provided in Table 1. The aquaponics system contained two big circular fish stocking tank, a conical shape fecal removal and collection tank and it is connected with the two rectangular Biofilter system, a CO_2 removal tank receiving water from biofilter tank finally the nutrition rich water entering in to the plant culture raceway. The nutrient removal water reached the final collection sump and the water again transferred to fish tank by the electric motor pump. The green house air system was maintained as 20°C±2°C with the help of greenhouse evaporative cooling pad (Water wall system).

Table 1. Total System water volume in a Greenhouse.

Tanks	Water volume	No of Tank
Fish Tank	7.754 m3	2
Mechanical filter	4.502 m3	2
Bio-filter	0.747 m3	2
CO_2 removal tank	0.186 m3	1
Cultivation tank	9.004 m3	4
Collection tank	0.209 m3	1
Total	57.95 m3	

Experimental setup and crop cultivation

The experimental Tilapia fishes (*Oreochromis niloticus*) were taken from Aquaculture Research Station, Falaj Hazza, UAEU and the fishes were stocked in the aquaponics fish stocking tank in the ratio of 120 fish/m^3. The tilapia was fed with commercially available 36% protein floating feed from Arabian Agricultural Services Company ARASCO, Saudi Arabia. Fishes were fed to satiation twice a day with the rate of 20g/ m^2 and fish weight ratio [33].

The cucumber and lettuce seeds were directly seeded on the rock wool (Neutralized with culture water) inserted in plastic cup and directly placed on the plant culture raceways on floated styrofoam sheets. The Cucumber plants were seeded in the ratio of 3 plants per square meter and the Lettuce seeded were in the ratio 17 plants per square meter. The total experimental period is prolonged to four months; Lettuce harvest period is 3 months and Cucumber harvest started from the second month to fourth month (3-month duration).

Growth and proximate composition analyses

Lettuce and Cucumber characteristics of each harvest was evaluated by morphological and yield parameters. The green house parameters and minerals analysis were also studied [34, 35].

Water quality parameter analyses

Water quality was monitored in the aquaponics system.

Statistical Analyses

The results were expressed as Mean ± SD. Statistical analyses were carried out by Analysis of Variance (one way ANOVA and subsequently post hoc multiple comparison with DMRT) considered as indicative of significance at $P < 0.05$, as compared to the control group. All calculations were performed using IBM SPSS statistics, version 28.0.0.0. (190) for Windows.

RESULTS

Water quality parameters and Mineral concentration in Aquaponics water

During the four-month experimental period, there were no symptoms of disease or pest infestation on either crop. The aquaponics system provided a fresh, healthy, and wealthy yield of Lettuce and cucumber. In this experimental period, the analyzed water quality values are provided in Table 2. As a result, the water's temperature shows no significant fluctuations in the system. The DO (Dissolved oxygen) level shows a significant reduction when compared with the first month, and it is maintained by the compressor air supply system. The pH level slightly decreased at the end of the month. Other water quality parameters include the following: TDS (Total Dissolved Solids), EC (Electrical conductivity), total ammonia nitrogen (TAN), dissolved oxygen (DO), and nitrate NO_3 levels, which show a noticeable increase in the final months. Also, the aquaponics water containing micro and macronutrients were analyzed at each fifteen-day interval, and the results are provided in Table 3. In that analysis, the major levels of elements (Ca, K, P, Mg, Fe, Mn, Mo, and Zn) show a noticeable increment in the aquaponics effluent water.

Table 2. Water quality parameters of the aquaponics water.

Months	Temp. (°C)	DO (mg/l)	pH	TDS (ppm)	EC (mV)	NH_{3v}(mg/l)	Nitrate (mg/l)	Nitrite (mg/l)
1	23.23±0.31a	7.86±0.43a	6.99±0.25a	334.83±11.11d	12.99±6.06d	0.14±0.05d	5.18±0.92d	0.10±0.04c
2	22.67±0.23a	6.74±0.15a	6.59±0.08a	405.23±38.94c	26.81±4.74c	0.73±0.15c	7.42±0.70c	0.26±0.07b
3	22.68±0.43a	6.27±0.01b	6.21±0.03a	564.76±53.25b	47.70±2.97b	1.44±0.45b	12.64±1.07b	0.25±0.07a
4	23.47±1.62a	5.86±0.29c	6.22±0.18b	819.29±142.18a	50.71±6.01a	2.46±0.53a	16.36±3.38a	0.23±0.07a

Each value is Mean±SD of triplicates.

Table 3. Aquaponics water contained mineral Nutrient profile (ppm).

Experiment Month		Ca	Na	K	Mg	P	Co	Fe	Mn	Mo	Zn
Initial		30.8	0.003	0.009	0.92	0.130	<0.009	30.2	<0.009	3.19	0.011
1	15th day	37.8	0.003	0.016	0.009	4.663	<0.009	46.7	2.519	3.90	0.010
	30th day	62.9	0.003	0.021	0.016	9.703	0.05927	49.3	8.754	6.77	0.036
2	45th day	75.0	0.003	0.026	0.016	5.44	0.089	52.9	10.35	8.0	0.032
	60th day	72.5	0.003	0.020	0.021	20.68	0.203	51.2	14.73	12.9	0.055
3	75th day	89.4	0.003	0.027	0.030	16.03	0.155	54.1	13.88	10.3	0.050
	90th day	47.7	0.003	0.018	0.011	9.41	0.025	46.8	6.66	5.3	0.023
4	105th day	148.2	0.003	0.032	0.036	18.98	0.073	77.6	21.12	24.3	0.016
	120th day	144.7	0.005	0.036	0.042	31.23	0.272	69.2	24.08	22.0	0.029

Each value is Mean±SD of triplicates.

Table 4. Proximate composition of harvested Cucumber and Lettuce.

Crops	Months	Moisture% (WB)	Ash (%)	Crude Protein (%)	Crude Fiber (%)	Fat (EE) (%)	NFE (%)
Lettuce	1	96.63±0.40a	22.10±0.57a	29.63±4.22a	14.37±1.33a	3.30±0.37a	34.53±3.51a
	2	96.31±32.02a	21.43±7.15a	28.13±8.62a	14.03±1.59a	3.60±1.08a	32.83±3.88a
	3	96.23±0.16a	23.43±0.90a	27.80±1.97a	13.83±0.25a	3.23±0.45a	31.67±2.80a
Cucumber	1	95.28±0.20a	16.09±2.02a	9.17±0.38a	16.75±3.74a	0.35±0.01a	52.64±3.69a
	2	95.58±0.49a	18.25±2.69a	9.62±0.32a	17.96±3.81a	0.37±0.02a	53.79±1.45a
	3	96.25±0.38a	17.50±0.77a	9.37±0.55a	15.57±2.25a	0.35±0.01a	52.81±2.72a

Each value is Mean±SD of triplicates.

The total proximate composition and mineral concentration of Lettuce and Cucumber

In this experiment, the total moisture, ash, protein, fiber, fat, and carbohydrates of the lettuce and cucumbers were measured and written down in Table 4. The results show that there are no significant differences in any of the parameters for each month of harvest, demonstrating that the culture conditions have no impact on the biochemical quality of the produced goods. Both crops' macro- and micronutrient contents were examined and listed in Table 5. Additionally, the elements did not significantly change across all harvesting times. The two outcomes clearly demonstrate the suitability of aquaponics cultivation conditions for this kind of mixed cultivation and the system's ability to preserve the biochemical integrity of the lettuce and cucumber.

Production performance of lettuce and cucumber

The yields of the lettuce and cucumber plants used in this study are shown in Table 6. When compared to the third month of production, the lettuce yields from the first two months show a significant increase in production, total yield, average height and weight, and overall performance. Over the course of the entire experimental period, the production performance of the cucumber cultivation shows no discernible variation. The cultivation of lettuce and cucumbers in an aquaponics system is very successful, according to the results. The first three months are ideal for growing lettuce in the open spaces left after growing cucumbers, and doing so gives us a double benefit.

DISCUSSION

This closed-loop system not only minimizes waste but also reduces the need for synthetic fertilizers and pesticides, making it a more environmentally friendly option. By harnessing the natural processes of fish waste decomposition and plant nutrient uptake, aquaponics creates a harmonious relationship between aquatic animals and plants [36]. Furthermore, this method requires less water compared to traditional farming practices, as water is continuously recycled within the system. The integration of aquaponics into our food production systems has the potential to address global food security challenges by providing a sustainable and reliable source of fresh produce [37, 38]. Additionally, it offers an alternative to intensive fisheries and aquaculture, which often contribute to overfishing and environmental degradation. As researchers continue to explore and optimize this innovative approach, aquaponics holds great promise for transforming our agricultural practices towards a more efficient and sustainable future [39].

In the present study, the water circulation system was kept at a temperature of 24°C, and the air system was kept at 20 to 22°C. Cucumber plant development and lettuce green production are both favored by this air temperature. Seed germination is regulated by different environmental factors, which should be optimum and depend on each variety [40]. The water's DO level was kept at the recommended level. High DO levels must be maintained in aquaponics systems for the wellbeing of plant roots and the removal of water toxins that have been lowered [12, 41].

The generation of beneficial organisms in the water medium can result from the continuous aeration of an aquaponics system. If a system has the right climatic conditions, bacteria, phytoplankton, and zooplankton can establish themselves and help the plants grow and stay healthy [42]. Additionally, although there was an enhanced level of ammonia, nitrate, and nitrite in this experiment, it did not reach lethal levels. Plants may be harmful when grown crops use ammonia and nitrates for growth since they are more readily absorbed by plants than ammonia nitrite. Increased ammonia concentrations can prevent plants from absorbing nutrients by changing the ionic capacity of the aqueous media [43].

Table 5. Macro and micro mineral composition (ppm) in the dried cucumber and lettuce plant.

Crops	Month	Ca	Na	K	Mg	P	S	Co	Cu	Fe	Mn	Mo	Zn
Lettuce	1	2.81± 0.35a	2.02± 1.06a	2.17± 0.83a	0.38± 0.06a	0.77± 0.05a	0.32± 0.04a	0.30± 0.06a	10.50± 0.70a	111.97± 20.86a	75.73± 12.60a	2.55± 0.34a	105.77± 18.86a
	2	2.62± 0.64a	1.99± 0.29a	2.52± 0.41a	0.40± 0.04a	0.80± 0.05a	0.33± 0.05a	0.33± 0.10a	10.57± 0.64a	111.80± 20.66a	73.60± 19.71a	2.39± 0.39a	104.97± 9.60a
	3	2.57± 0.06a	2.17± 0.22a	0.34± 0.03a	0.36± 0.03a	0.77± 0.05a	0.36± 0.02a	0.49± 0.60a	10.47± 0.64a	117.37± 24.75a	91.83± 14.57a	8.80± 2.19a	106.63± 5.56a
Cucumber	1	72.6± 0.43a	11.73± 6.72a	20.67± 0.13a	29.23± 3.12a	68.73± 4.04a	33.68± 3.61a	0.21± 0.00a	12.33± 0.07a	144.02± 15.84a	11.32± 3.05a	3.44± 0.02a	39.98± 0.23a
	2	68.91± 4.14a	13.01± 5.70a	19.11 ± 13.46a	32.07± 3.58a	62.15± 7.43a	33.56± 3.43a	0.15± 0.06a	11.11± 1.26a	133.23± 17.91a	12.23± 4.36a	2.70± 0.70a	39.88± 0.30a
	3	64.46± 0.38a	14.03± 6.44a	18.16± 10.48a	29.49± 3.16a	57.29± 3.47a	33.49± 3.38a	0.10± 0.00a	10.97± 0.06a	135.78± 16.54a	12.30± 311a	2.87± 0.01a	39.49± 0.23a

Each value is Mean±SD of triplicates.

Table 5. Aquapnics Cultivated Lettuce and Cucumber yield.

Crops	Month	No of plant	Total production(Kg)	Average Weight (Gm)	Average Height (Cm)	Total No of products	Yield/m2 (Kg)
Lettuce	1	2000	530.12 ±13.5a	271.69±19.54a	26.45±1.10a	1949 ± 48a	25.63±0.21a
	2	2000	518.42±25.2a	273.12±24.04a	23.82±1.05b	1899 ± 59ab	26.45±0.52a
	3	2000	325.5±34.5b	216.61±35.80b	21.58±0.55c	1500 ± 45b	21.43±0.62b
Cucumber	1	347	817.23±140.58a	65.37±4.42a	11.82±0.17a	12604.00±3002.86a	2.36±0.41a
	2	347	750.98±128.63a	66.87±3.08a	11.97±0.10a	11198.81±1408.56a	2.16±0.37a
	3	347	787.30±229.58a	64.79±7.28a	11.94±0.20a	12429.18±4940.59a	2.27±0.66a

Each value is Mean±SD of triplicates.

The majority of the nitrogen that is now present is absorbed by plant roots and used as a building block for the creation of proteins and other nitrogen molecules. Both nitrates and nitrites are present in foods as foreign additions and as unwanted contaminants [44]. Furthermore, maintaining proper pH levels is crucial for optimal nutrient uptake by the plants [45]. In addition to nutrient and pH management, it is important to ensure adequate oxygenation of the root zone. Oxygen is essential for root respiration and nutrient absorption, so proper aeration techniques such as air stones or diffusers should be employed [46].

The analysis of the aquaponics water revealed significant changes in various parameters. The levels of TDS (Total Dissolved Solids), EC, TAN (total ammonia nitrogen), DO, and nitrate NO3 exhibited a noticeable increase during the final months of observation. This suggests a potential shift in the water quality and nutrient composition within the system. Additionally, the analysis of micro and macronutrients in the aquaponics water at fifteen-day intervals demonstrated a substantial rise in the major elements such as Ca, K, P, Mg, Fe, Mn, Mo, and Zn. These findings indicate an evident increment in the concentration of essential nutrients present in the aquaponics effluent water. The observed changes highlight the dynamic nature of this closed-loop system and emphasize the importance of regular monitoring to ensure optimal conditions for plant growth and fish health.

In the current study, lettuce and cucumber were grown together with observable production and yield performance. In the first and second months, lettuce production performed better than in the third month, but aside from production, there were no discernible differences in the lettuce's physical quality. Throughout the experimental period, cucumber production performance exhibited no appreciable changes, and the cucumber's physical quality (Height, weight, leaf no's and physical observation) followed a similar pattern. It is worth noting that due to the cucumber's impressive density and growth in the third month, it is possible that it absorbed a substantial amount of nutrients from the system, resulting in a reduction in the lettuce crop.

In the current study, lettuce and cucumber were grown in an aquaponics system, and data on biochemical composition and mineral concentrations were collected. These findings don't indicate any appreciable variations between harvesting months. The biochemical and mineral concentrations of both lettuce and cucumber followed the same pattern throughout all experimental periods, demonstrating that the crops made good use of the nutrients in the aquaponics water and that environmental factors had no impact on the crops' quality. This suggests that the aquaponics system provided a stable and consistent environment for the growth of lettuce and cucumber. This is an encouraging finding as it highlights the potential of aquaponics as a sustainable method for cultivating high-quality produce. These results provide valuable insights for further optimizing aquaponics systems and maximizing crop productivity while maintaining consistent nutritional value. Similar results of the current biochemical and mineral concentrations were reported in lettuce and cucumber grown in aquaponics [25, 47, 48].

CONCLUSION

The lettuce cultivation in the aquaponics system exhibits remarkable success, as evidenced by the significant increase in production, total yield, average height and weight, and overall performance. Throughout the entire experimental period, there is no discernible variation in the production performance of cucumber cultivation. This successful integration of lettuce and cucumbers in the system presents a unique advantage. By utilizing the open spaces after growing cucumbers, the first three months prove to be ideal for cultivating lettuce. This approach not only maximizes space utilization but also provides a double benefit in terms of yield and overall efficiency. The results clearly demonstrate the effectiveness of this innovative aquaponics system for enhancing crop productivity and optimizing resource utilization. Remarkably, regardless of the variations in culture conditions, there were no substantial changes observed in the nutrient levels across different harvesting times. These findings unequivocally establish that aquaponics cultivation conditions are highly conducive for mixed cultivation, as they effectively maintain the biochemical integrity of both lettuce and cucumber. The results highlight the robustness and reliability of this innovative system, emphasizing its potential for sustainable and high-quality food production.

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