Asian Journal of Biology

Volume 20, Issue 5, Page 12-22, 2024; Article no.AJOB.114165
ISSN: 2456-7124

Water Quality and Growth Performance of Nile Tilapia (*Oreochromis niloticus*), Chia (*Salvia hispanica*) and Lemon Grass (*Cymbopogon citratus*) in a Media-based Aquaponics System

Zipporah Gichana [a*]

[a] *Department of Environment, Natural Resources & Aquatic Sciences, School of Agriculture & Natural Resource Management, Kisii University, Kisii, Kenya.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/AJOB/2024/v20i5402

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114165

Original Research Article

Received: 14/01/2024
Accepted: 18/03/2024
Published: 22/03/2024

ABSTRACT

High ammonia levels in enclosed fish production systems negatively impact fish growth and hinder optimum production. The objective of this study was to evaluate the (i) biofiltration potential of chia (*Salvia hispanica*) and lemon grass (*Cymbopogon citratus*) (ii) the influence of the plant filters on water quality and fish growth in an aquaponic system. Treatments included a control-without plants, *S. hispanica*, and *C. citratus* aquaponic systems. The study was conducted for 3 months in Aqualife fish farm, Machakos, Kenya. Water quality parameters, growth performance of fish and plants were monitored during the experiment. The plant treatments significantly (P< 0.05) reduced ammonia levels compared to the control (0.07 ± 0.17 mgL^{-1}). There was a remarkable 32-fold decrease in ammonia compared to the hydroponic inlet. Planted aquaponic systems significantly (P < 0.05)

**Corresponding author: E-mail: zippgichana@gmail.com;*

reduced nitrite and nitrate concentrations compared to the control, indicating effective nutrient cycling and improved water quality. Notably, both *S. hispanica* (115. 5 ± 3.2 g) and *C. citratus* (130.3 ± 3.32 g) systems significantly ($P < 0.05$) boosted the growth performance of *O. niloticus* compared to the control (113. 5 ± 3.2 g). *C. citratus* performed better (450 ± 9.17 g) than *S. hispanica* (217.6 ± 2.52 g). These findings highlight the potential of the plants as sustainable and efficient biofilters**,** enhancing overall aquaponic system performance and contributing to a more productive and environmentally friendly approach to food production.

Keywords: Aqua agriculture; grow bed; hydroponics; nitrification; plant uptake.

1. INTRODUCTION

The current global population is 7.9 billion, with a projected increase to 9.8 billion by 2050. This will increase global food demand by 60% [1]. Feeding the growing population necessitates striking a balance between food production and waste generation to ensure a sustainable environment. However, food production is an anthropogenic activity that has increased the use of fertilizers and available freshwater resources [2,3]. Freshwater scarcity is one of the most pressing global issues, affecting more than 40% of the world's population [4,5]. Furthermore, conventional food production systems are unable to meet the growing demand for the world's population due to arable land loss, water quality and quantity limitations, soil degradation, and nutrient depletion [6]. Rapid population growth, combined with increased competition for scarce land and water resources, poses a formidable challenge in producing enough food to feed the world's growing population [7].

The challenge of feeding a growing population is further intensified by climate change, a major driver of global hunger and malnutrition. In 2020, the number of undernourished people reached a staggering 768 million, highlighting the fragility of our food systems in the face of rising temperatures, shifting weather patterns, and extreme weather events [8]. These challenges necessitate the development of innovative and sustainable solutions such as aquaponics. Aquaponics are closed looped systems that improves food production while reducing reliance on water resources and environmental impact [9,10]. Aquaponics combines fish farming and hydroponics to recycle nutrients, reduce waste, and improve resource efficiency. This efficient use of water makes it particularly valuable in areas prone to drought and scarcity [11,12,13]. The integrated aqua-agriculture system addresses the water – food nexus of the United Nations Sustainable Development Goals (Goal 2: Zero hunger, Goal 14: Life below water and Goal 6: Clean water and sanitation) [7,14].

Aquaponic studies have demonstrated the ability of plants to utilize nutrients from aquaculture wastewater while maintaining water quality [15,14,16,17,18]. However, aquaponic systems present unique challenges, including managing nutrient concentrations to provide optimal concentrations for plants while minimizing negative effects on fish, bacteria, and the environment [19]. Furthermore, the type of grow bed can influence nutrient concentration in the aquaponic system. Media in the ebb and flow bed serves as a substrate for nitrifying bacteria, as well as a solid filtering and mineralization medium, increasing the concentration of nutrients available for plant uptake [18]. Fish density, protein levels in feed, feeding rate, metabolic conversion, excretion, uneaten feed, fish excretes and plant nutrient requirements can all influence nutrient concentration in aquaponic systems [18,20]. Understanding nutrient dynamics is therefore necessary to properly manage and balance nutrient concentrations in aquaponic systems. Our study investigated this critical aspect in a media based aquaponic system by determining the influence of lemon grass (*Cymbopogon citratus*) and chia (*Salvia hispanica*) on water quality parameters and growth performance of Nile tilapia (*Oreochromis niloticus*). Understanding these interactions can help improve aquaponic production for both plants and fish.

2. MATERIALS AND METHODS

2.1 Study Site

This study was conducted at Aqualife fish farm, Kithini about 8 kilometers from Machakos town, Kenya (-1.525134° latitude and 37.185891° longitude). Machakos is located 63 kilometers southeast of the capital city, Nairobi. Machakos experiences a hot and dry climate with two distinct rainy seasons: March–May (long rains) and October–December (short rains). The annual rainfall ranges between 500 and 1300 millimeters, and at an altitude of 1620 meters above sea level. The average monthly temperature ranges from 18°C to 25°C, with March and October being the hottest months and July being the coldest. Nighttime temperatures can drop as low as 13°C, with July lows of 10°C [21].

2.2 Experimental Design

Nine independent aquaponic systems were installed under a greenhouse to protect the fish and plants from extreme weather events and external threats as well as provide optimum growth conditions (Plate 1). A completely randomized design with three treatments (control - with no plants, *Salvia hispanica* and *Cymbopogon citratus*) and 3 replicates was used in the experiment. Each unit consisted of a fish tank (water volume 400 L, height 0.75 m) to hold fish; plastic mechanical filter (volume 500 L, 0.75 m) filled with gravel (Ø 5-30 mm) ; a sump (volume 500 L, 0.75 m) where wastewater from the fish tanks was collected before pumping to the biofilters; plastic biofilter units (600 L, 0.75 m) and 3 hydroponic grow beds (1.5×0.5×0.8 m) filled with gravel (Ø 5-15 mm). The gravel functioned as a biofilter and a plant growing medium. The system's components: fish tanks, hydroponic grow beds, sumps, and biofilter tanks were gravity-fed and multi-tiered. Eliminating the need for additional pumps and simplifying operations. Centrifugal water pumps (DPP 60, 0.5 HP, 2500 L.h-1 0.37 kW, Davis and Shirtliff) were used to lift water into the biofilters and fish tanks. The flow rate to each fish tank and hydroponic grow bed was maintained at 6 ± 0.24 L/min and 1.42 ± 0.23 L/min respectively. The fish tanks were equipped with porous aeration discs connected to an aeration pump (>0.03 Mpa, 60 L/min, V-60, Aqua Forte). Polyvinyl chloride (PVC) pipes were installed to continuously recirculate water from the fish tanks to the biofilters then back to the fish tanks.

Plate 1. Experimental set up of the aquaponic system with the three different treatments (a) *S. hispanica* (b) *C. citratus* , (c) Control without plants and (d) recirculating aquaculture system

2.3 Water Quality Parameters

The culture water within each unit was not exchanged, with daily manual refills were done to compensate for water lost through evapotranspiration. In situ measurements of select water quality parameters was done twice daily (temperature, pH, dissolved oxygen (DO) and electrical conductivity) using a multiparameter meter (HQ40d, HACH, Loveland, Colorado, USA). Triplicate water samples were collected from fish tanks, hydroponic inlet and outlets every two weeks, and analyzed for ammonia, nitrite, nitrate and soluble reactive phosphorus (SRP) following APHA standard procedures [22]. The nutrient removal rate, accounting for both plant uptake and other biological transformations, was determined using the following equation [23].

Removal rate= (Concentration of the inlet-concentration of outlet)/ (Concentration of inlet) x 100

2.4 Experimental Fish and Plants

Oreochromis niloticus, a widely cultured fish in Kenya with high market demand (Omasaki et al., 2016) was used for the experiment. One month prior to the start of the experiment, the fish were stocked in the aquaponic systems to acclimatize them to the new environment and allow bacteria to naturally colonize the biofilter substrates [24]. Each fish tank was randomly stocked with 50 fish obtained from a commercial farm (Kamuthanga Fish Farm, Machakos) with an initial live weight of 75 ± 5.6 g and stocking density of 7.5 kg m-3. The fish were manually fed to satiation twice a day (9.00 hrs and 4.00 hrs) using compounded extruded pellets (Ranaan, Israel, composition: 30% crude protein, 8% crude fat, 30.5% nitrogen-free extracts (NFE), 10% ash, 9% crude fibre and 11% moisture). Fish feed consumption was calculated and recorded daily. *S. hispanica* and *C. citratus* seedlings were grown in seedling trays three weeks prior to the start of the experiment. After two weeks of germination, seedlings were transferred to individual hydroponic units at a density of 36 plants per unit. The control group remained unplanted for comparison purposes. Throughout the experiment, no pesticides or antibiotics were used in water or feed.

2.5 Fish Growth

Individual fish weights and lengths were collected every two weeks for all fish within each experimental unit, providing a comprehensive dataset for growth analysis. Fish weight measurements were taken using an electronic weighing balance (readability 0.01 mg) and lengths taken using a measuring board with a ruler to the nearest 0.1 mm. The mortality of fish was recorded daily. Growth performance was measured in terms of weight gain, specific growth rate (SGR), survival rate (SR), and feed conversion ratio (FCR), as shown in the equations below.

Weight gain (g) = (Final weight (g) - initial weight (g))/initial weight

$$SGR = [(\ln W_f - \ln W_i) /t]\ 100$$

$$SR = [(N_0 - N_t)/N_0\ ]100$$

where N_0 and N_t are fish numbers at time 0 and at time t, W_i and W_f are initial and final mean wet weight in grams (g); ln is the natural logarithm and t is time in days.

FCR = Total weight of dry feeds given (g)/ Total weight gain (g)

2.6 Plant Growth

Initial and final plant weight measurements were obtained at the beginning and end of the experiment with the aid of an electronic weighing balance. To quantify the rate at which the plants grew, we determined their relative growth rate (RGR) based on the difference in their fresh weight over time.

$$RGR = (\ln W_2 - \ln W_1) / (t_2 - t_1)$$

where W_2 and W_1 are weights at time t_2 and t_1, which are initial and final periods and ln is the natural logarithm.

2.7 Data Analysis

Selected water quality parameters including temperature, pH, dissolved oxygen (DO), ammonia, nitrite, nitrate and soluble reactive phosphorus (SRP) fish and plant growth parameters (length & weight) were recorded in Microsoft Excel based on treatment groups and presented as means ± SD. The normality of data was checked using the Kolmogorov-Smirnov test. One way ANOVA was used to determine significant differences in water quality parameters and fish growth performance across aquaponic treatments. Significant differences were further analyzed using Tukey's HSD test to identify specific differences. Plant weight differences were analysed using t-test. The percentage survival of fish was calculated as a proportion of fish that remained alive and fish that were initially stocked. Box and whisker plots were used to visually compare differences in plant weight and relative growth rate across planted treatments. Differences between means were considered significant at $P < 0.05$. Statistical analyses were performed using the IBM SPSS Statistics for Windows (version. 21.0, IBM Corp., Armonk, NY, USA).

3. RESULTS AND DISCUSSION

3. 1 Water Quality Parameters

Water temperature fluctuated slightly between 23.3 and 25.6 °C, offering a mild and stable environment for both fish and plants [25,26]. The temperature remained slightly below the optimal range for tilapia growth (27-29 °C) across all treatments. pH values clustered around neutral, ranging from 7.65 to 7.87 (Table 1), suggesting effective buffering capacity within the aquaponic systems. Dissolved oxygen (DO) was maintained between 4.54 and 6.53 mgL^{-1}, which falls within the range considered optimal for *O. niloticus* (5.0 – 7.7 mgL^{-1}), plant growth and performance of nitrifying biofilters (>2 mgL^{-1}) [27]**.** pH can have a significant impact on plant growth as it affects the availability of boron, zinc, copper, manganese, and iron. It can also interfere with phosphorus, magnesium, molybdenum, and calcium absorption, slowing plant development. The ideal pH range for optimal nutrient uptake and growth is between 5.5 and 6.5 [28]. The pH levels exceeded the recommended range (5.5-6.5) for hydroponic plants but were within recommended levels (6.5 – 9.0) for aquaponic systems [29,30].

Fish primarily excrete ammonia, a nitrogenous waste product, through their gills. This ammonia is typically converted by beneficial bacteria into nitrite and then nitrate which is less toxic to fish [31]**.** In this study, hydroponic inlets had the highest ammonia levels (1.9 ± 0.23 mgL^{-1}), highlighting the importance of plants in nutrient uptake. The absence of plants in the control system resulted in significantly higher ($P < 0.05$) nutrient concentrations compared to systems with *C. citratus* and *S. hispanica*. This is particularly evident in ammonia levels, which were nearly twice as high in the control (0.07 ± 0.17 mgL^{-1}) than the planted systems (0.04 ± 0.14 mgL^{-1} for *C. citratus* and 0.06 ± 0.05 mgL^{-1} for *S. hispanica*). The measured ammonia values were within recommended optimal range (< 1.00 $mgL^{-1)}$ for *O.niloticus* [31] except for the control treatment. These findings align with previous studies [16,17,32,33], which also reported elevated ammonia levels in control systems without plants. The presence of plants clearly contributed to more effective ammonia removal and enhanced growth of *O*. *niloticus* in the aquaponics system.

The observed nitrate levels remained within the established safety range (< 100 mgL^{-1}) for aquaponics [34]. This suggests that the presence of plants in our aquaponics treatments improved nitrate bioremediation in the culture water. Furthermore, nitrate is a relatively harmless form of nitrogen and is the preferred nitrogen source for the majority of plant species [35]. Nitrate levels (1.49 ± 0.05 -1.61 ± 0.09 mgL^{-1}) and minimal nitrite accumulation (0.16 ± 0.01 – 0.21 ± 0.04 mgL^{-1}) strongly suggest the presence of a complete nitrification process. This crucial step in the nitrogen cycle efficiently converts toxic ammonia into plant-usable forms, creating a healthy and balanced environment for both plants and fish [16,36]. The control system exhibited significantly higher phosphorus levels (1.42 ± 0.16 mgL^{-1}) compared to planted systems with *C. citratus* (0.85 ± 0.17 mgL^{-1}) and *S. hispanica* (0.9 ± 0.12 mgL^{-1}), representing a 57% increase. This finding aligns with the role of plants in absorbing and accumulating phosphorus through root uptake and biomass production [36].

Plants play a vital role in reducing nutrients from wastewater. However, the nutrient removal capacity of the plants can be affected by the growth stage, nutrient requirements and the activity of ammonia-oxidizing bacteria [28,37,38]. Young plants have lower nutrient requirements, which significantly increase during the vegetative growth phase [39]. Additionally, plant roots in aquaponic systems provide a substantial surface area for beneficial microbes that convert harmful ammonia into nitrates via oxidation [40]. In this study, the removal rates for ammonia, nitrites, and nitrates were not significantly different in the control, *C. citratus*, and *S. hispanica* systems. However, *C. citratus* (55.8%) and *S. hispanica* (55.9%) recorded significantly high ($P < 0.05$) ammonia removal rates. The two systems had relatively high ammonia removal rates (56%), indicating their efficacy in managing this potentially harmful nitrogenous compound. This highlights the critical role of plants in maintaining

Table 1. Water quality parameters in the aquaponic systems with different plants (Means ± Standard Deviation)

Parameters	Hydroponic inlet	Control	*C. citratus*	*S. hispanica*	*P* value
DO (mgL^{-1})	5.5 ± 0.06	4.8 ± 0.07	5.4 ± 0.04	5.2 ± 0.06	0
Temperature (°C)	24.3 ± 0.18	24 ± 0.25	23.8 ± 0.22	24 ± 0.20	0.29
pH	7.7 ± 0.02	7.6 ± 0.05	7.6 ± 0.04	7.7 ± 0.02	0.17
Ammonia (mgL^{-1})	1.92 ± 0.23	0.07 ± 0.17	0.04 ± 0.14	0.06 ± 0.05	0
Nitrite (mgL^{-1})	0.26 ± 0.01	0.21 ± 0.04	0.16 ± 0.01	0.16 ± 0.01	0.01
Nitrate (mgL^{-1})	2.54 ± 0.13	1.61 ± 0.09	1.49 ± 0.05	1.49 ± 0.08	0
Phosphate (mgL^{-1})	2.01 ± 0.19	1.42 ± 0.16	0.85 ± 0.17	0.9 ± 0.12	0

P-value: Level of significance of water quality parameters among aquaponic systems (P<0.05)

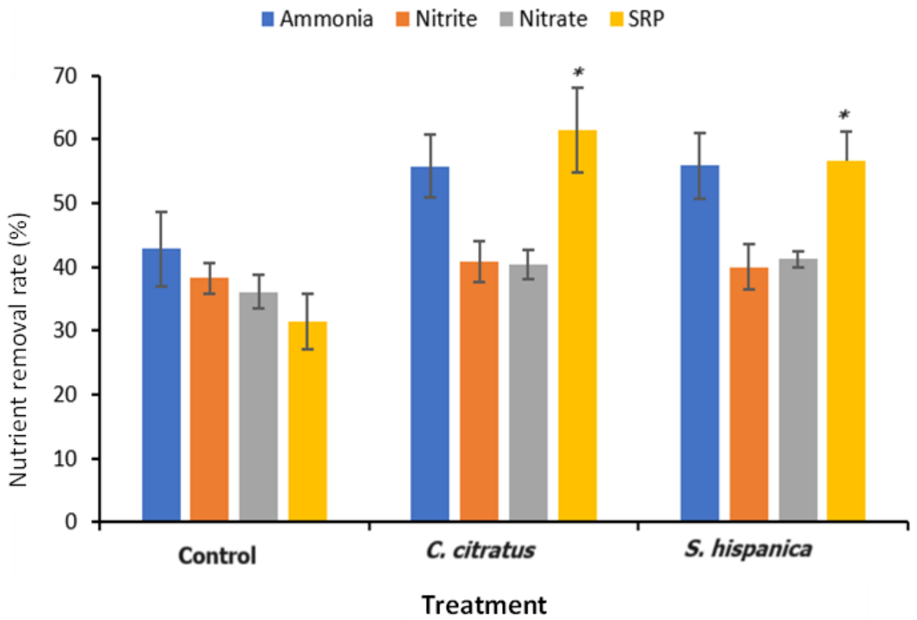

Fig. 1. Nutrient removal rates (ammonia, nitrite, nitrate & soluble reactive phosphorus (SRP)) in the control, *C. citratus* and *S. hispanica* aquaponic systems

*Aquaponics treatment: significant from the control, * P < 0.05*

water quality suitable for fish. Plants absorb nutrients through their root system, which provide a surface area for beneficial bacteria to grow, allowing ammonia to be converted into nitrites and nitrates, which are usable for plant growth [14,41]. The high ammonia removal rate of *C. citratus* could be attributed to specific physiological or morphological traits that improve nutrient uptake and processing compared to *S. hispanica*. In addition, the extensive root network system of *C. citratus* probably allowed the attachment of more beneficial bacteria that converted ammonia to less toxic nitrate [32]. The mean SRP removal rate was higher ($P < 0.05$) in *C. citratus* (61.5 ± 6.6%) and *S. hispanica* (56.6 ± 4.6%), but low in the control aquaponics (31.5 ± 4.4%). The findings suggest that *C. citratus* and *S. hispanica* have a more efficient mechanism for phosphorus uptake and utilization, a crucial nutrient for plant growth.

3.2 Fish Growth Performance

The final weight gain of fish was not significantly different across all treatments (Table 2). However, weight gain, FCR, and specific growth rates differed significantly among the treatments. In the *C. citratus* system, the FCR was significantly low (1.7 ± 0.01) and higher (2.1±0.01) in the control aquaponic system ($P<0.05$). High ammonia levels in the control system probably suppressed feed intake or resulted in incomplete feed consumption compared to the planted treatments. Fish frequently exhibit this behavior as a stress response to chronic ammonia exposure. A similar phenomenon, with *O. niloticus* showing a decrease in FCR as ammonia concentrations increased was reported [42]. This is consistent with [43], who attributed the negative correlation between ammonia and specific growth rate (SGR) to reduced feed intake. The *C. citratus* system provided an environment for fish to thrive, promoting both significant weight gain (60.2 ± 2.79 g) and faster growth (1.04 ± 0.58% d^{-1}) compared to other treatments. The extensive root network of *C. citratus* enhanced biofiltration, leading to improved water quality and increased fish growth. This is consistent with the findings of [44] and [45], who reported a positive correlation between decreased ammonia concentrations and increased fish growth rate. This remarkable performance is further underscored by the system's high feed conversion efficiency (FCR 1.7 ± 0.07), indicating optimal utilization of feed for growth. The higher survival rate of *O. niloticus* in the *C. citratus* system (92.6 ± 2.0%) compared to the control (83.0 ± 2.0%) suggests that *C. citratus* provided a more favourable and healthier environment for fish. This might be attributed to the effective removal of nutrients through biological processes including nitrification and plant uptake [23]. The FCR in this study were comparable with those observed by [36] and within the recommended range (1.5-2.0) for *O.niloticus* grown in recirculating systems [46].

3.3 Plant Growth Performance

Plant growth parameters (weight and relative growth rates) are presented in Fig. 2. *Cymbopogon citratus* had a significantly higher (*P* = 0.00) mean weight, (450 ± 9.17 g) twice the weight of *S. hispanica* (217.6 ± 2.52 g). The relative growth rate was also significantly higher *(P* = 0.03) in *C. citratus* than *S. hispanica* (0.04 ± 0.01 g d^{-1}). This study suggests that the plants can thrive in an aquaponic system but *C. citratus* had better growth due to its high nutrient removal efficiency. This efficiency translates to more available nutrients for the plant, leading to more weight gain and a faster growth rate [23]. The growth rate of *S. hispanica* was comparable to the values obtained by [47], who studied the integration of *S. hispanica*, *Brassica rapa*, *Lactuca sativa*, *Beta vulgaris*, *Ocimum basilicum, Solanum lycopersicum*, and *O. niloticus*. Our study revealed variations in the ability of *C. citratus* and *S. hispanica* to utilize nutrients from aquaculture wastewater. This could be attributed to their growth characteristics, tolerance to pollutants, redox conditions in the root zone, and microbial activities. These findings are consistent with those reported in a media-based aquaponics system [16]. According to the findings, *C. citratus* and *S. hispanica* can effectively reduce aquaculture effluents while improving water quality for fish production.

Table 2. Growth performance of *O. niloticus* cultured in in the control, *C. citratus* and S. *hispanica* aquaponic systems

Parameters	Control	*C. citratus*	*S. hispanica*	*P* value
Fresh final weight (g)	115.5 ± 7.72	130.3 ± 3.32	113.5 ± 3.2	0.02
Fresh weight gain (g)	45.4 ± 3.88	60.2 ± 2.79	43.4 ± 1.47	0.012
Feed conversion ratio (FCR)	2.1 ± 0.01	1.7 ± 0.01	1.65 ± 0.06	0.002
Specific Growth Rate (SGR) (% d^{-1})	0.83 ±0.24	1.04 ± 0.58	0.8 ± 0.01	0.008
Survival rate (%)	83 ± 2.0	92.6 ± 2.0	88.1 ± 2.67	0.59

P-value: Level of significance of fish growth among aquaponic treatments (P<0.05)

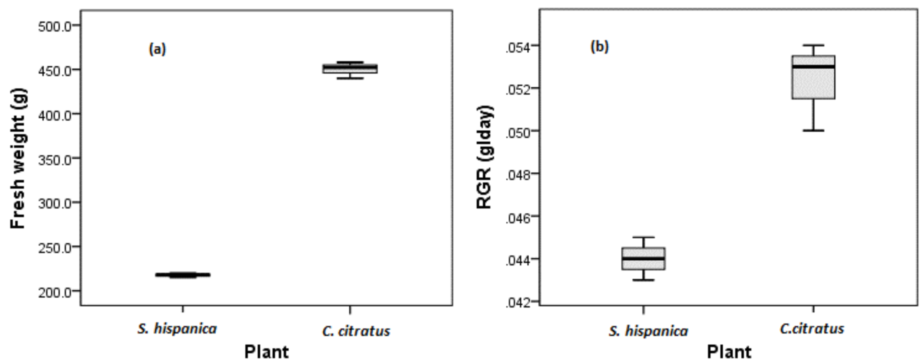

Fig. 2. Box and whisker plots of (a) plant mean weight and (b) relative growth rate (RGR) in the aquaponic system

4. CONCLUSION

This study investigated the influence of *S. hispanica* and *C. citratus* on water quality and growth of *O. niloticus.* The findings suggest both plants significantly reduced ammonia levels compared to the control, highlighting their ability to manage nitrogenous waste. However, *C. citratus* exhibited high nutrient removal capacity compared to chia and the control. Fish weight gain, growth rate and survival rate were significantly higher in the lemon grass system compared to others, suggesting a more favourable environment for the growth and health of *O. niloticus*. Both plants thrived in the aquaponic system, but *C. citratus* showed significantly better growth than *S. hispanica*. The high growth performance can be attributed to higher nutrient removal efficiency. Our study emphasizes the importance of plants in maintaining water quality in aquaponic systems. Moreover, integrating *C. citratus* in aquaponic systems can significantly reduce harmful ammonia levels, resulting in a healthier environment for fish and promoting overall system stability.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. United Nations (UN). World population prospects 2019. Population Data, File: Population Growth Rate, Median Variant tab. United Nations Population Division; 2019a.
   Available:https://population.un.org/wpp.
   Accessed 24 February 2024
2. Nyakeya K, Kipkorir KGK, Nyamora JM, Odoli CO, Kerich E. Dynamics of hydrology on the physico-chemical water quality parameters and trophic state of Lake Baringo, Kenya. Africa Environmental Review Journal. 2018;3(1):94-107.
   Available:https://doi.org/10.2200/aerj.v3i1.67
3. Gichana Z, Njiru M, Raburu PO, Masese FO. Effects of human activities on macroinvertebrate community structure and water quality in the upper catchment of Mara River Basin. Lakes and Reservoirs: Research and Management. 2015;20:128–137.
4. Nyakeya K, Masese FO, Gichana Z, Nyamora JM, Getabu A, Onchieku J, et al. Cage farming in the environmental mix of Lake Victoria: An analysis of its status, potential environmental and ecological effects, and a call for sustainability. Aquatic Ecosystem Health and Management. 2023; 25(4):37–52.
5. Ungureanu N, Vlădut V, Voicu G. Water scarcity and wastewater reuse in crop irrigation. Sustainability. 2020;12(21):9055.
   Available:https://doi.org/10.3390/su12219055
6. Bindraban PS, van der Velde M, Ye L, Van den Berg M, Materechera S, Kiba DI, et al. Assessing the impact of soil degradation on food production. Current Opinion in Environmental Sustainability. 2012;4:478-488.
   Available:https://doi.org/10.1016/j.cosust.2012.09.015
7. United Nations (UN). Every Year, 12 million hectares of productive land lost, secretary-general tells desertification forum, calls for scaled-up restoration efforts, smart policies. The seventh Kubuqi International Desert Forum, in Kubuqi Desert, China, on 27 to 28 July; 2019b.
   Available:https://www.un.org/press/en/2019/sgsm19680.doc.htm.
   Accessed 22 February 2024.
8. Food and agricultural organisation (FAO). The State of Food Security and Nutrition in the World Report 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Food and agricultural organisation, Rome, Italy; 2021.
   Available:https://www.fao.org/3/cb4474en/cb4474en.pdf.
   Accessed 22 February 2024.
9. Gichana ZM, Liti D, Waidbacher H, Zollitsch W, Drexler S, Waikibia J. Waste management in recirculating aquaculture system through bacteria dissimilation and plant assimilation. Aquaculture International. 2018;6:1541-1572.
   Available:https://doi.org/10.1007/s10499-018-0303-x
10. Llanos J, Border P. A resilient UK food system; 2020.

Available:https://post.parliament.uk/research-briefings/post-pn-0626/.

Accessed 20 January 2024.

11. Wafula AE, Gichana Z, Onchieku J, Chepkirui M, Orina SP. Opportunities and challenges of alternative local biofilter media in recirculating aquaculture systems. Journal of Aquatic & Terrestrial Ecosystems. 2023;1(1):73-81.
12. Martins CIM, Eding EH, Verdegem MCJ, Heinsbroek LTN, Schneider O, Blancheton, JP, et al. New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. Aquacultural Engineering. 2010;43:83-93.

    Available:https://doi.org/10.1016/j.aquaeng.2010.09.002
13. Gichana Z, Liti D, Drexler S, Zollitsch W, Meulenbroek P, Wakibia J, et al. Effects of aerated and non-aerated biofilters on effluent water treatment from a small-scale recirculating aquaculture system for Nile tilapia (*Oreochromis niloticus*). Die Bodenkultur: Journal of Land Management, Food and Environment. 2019; 70(4):209-219.

    Available:https://doi.org/10.2478/boku-2019-0019
14. Gichana Z, Liti D, Wakibia J, Ogello E, Drexler S, Ondiba R, et al. Efficiency of pumpkin (*Cucurbita pepo*), sweet wormwood (*Artemisia annua*) and amaranth (*Amaranthus dubius*) in removing nutrients from a small-scale recirculating aquaponic system. Aquaculture International. 2019;27: 1767-1786.

    Available:https://doi.org/10.1007/s10499-019-00442-x
15. Oladimeji AS, Olufeagba SO, Ayuba VO, Solomon SG, Okomoda VT. Effects of different hydroponics growth media on water quality and plant yield in a Catfish-pumpkin Aquaponics system. Journal of King Saud University – Science. 2020;32:60–66.
16. Gichana Z, Meulenbroek P, Ogello E, Drexler S, Zollitsch W, Liti D, et al. Growth and nutrient removal efficiency of sweet wormwood (*Artemisia annua*) in a recirculating aquaculture system for Nile Tilapia. Water. 2019;11(5): 923.

    Available:https://doi.org/10.3390/w11050923
17. Nuwansi KKT, Verma AK, Prakash C, Tiwari VK, Chandrakant MH, Shete AP, et al. Effect of water flow rate on polyculture of koi carp (*Cyprinus carpio* var. koi) and goldfish (*Carassius auratus*) with water spinach (*Ipomoea aquatica*) in recirculating aquaponic system. Aquaculture International. 2016; 24(1):1-9.

    Available:https://doi.org/10.1007/s10499-015-9932-5
18. Goddek S, Espinal CA, Delaide B, Jijakli MH, Schmautz Z, Wuertz S, et al. Navigating towards decoupled aquaponic systems: A system dynamics design approach. Water. 2016;8(7):303.

    Available:https://doi.org/10.3390/w8070303
19. Goddek S, Delaide B, Mankasingh U, Ragnarsdottir KV, Jijakli H, Thorarinsdottir R. Challenges of sustainable and commercial aquaponics. Sustainability. 2015;7:4199–4224.
20. Maucieri C, Nicoletto C, Zanin G, Birolo M, Trocino A, Sambo P, et al. Effect of stocking density of fish on water quality and growth performance of European Carp and leafy vegetables in a low-tech aquaponic system. PLoS ONE. 2019; 14(5):e0217561.

    Available:https://doi.org/10.1371/journ al.pone.0217561
21. Ngugi R, Mureithi M, Kamande P. Climate forecast information: The status, needs and expectations among smallholder agro pastoralists in Machakos District, Kenya. International Journal of Current Research. 2011;3(11):6–12.
22. American Public Health Association (APHA). American water works association and world environment federation. Standard methods for the examination of water and wastewater, 21st ed. American Public Health Association, Washington D.C., USA. 2005;1650.
23. Boxman SE, Nystrom M, Ergas SJ, Main KL, Trotz MA. Evaluation of water treatment capacity, nutrient cycling, and biomass production in a marine aquaponic system. Ecological Engineering. 2018;120:299-310.

    Available:https://doi.org/10.1016/j.ecoleng.2018.06.003
24. Delong DP, Losordo TM. How to start a Biofilter. SRAC Publication-Southern

Regional Aquaculture Center. 2012;3: 1-4.
Available:https://www.scribd.com/document/214107096/SRAC-How-to-Start-a-Biofilter Accessed 22 February 2024.

25. El-Sayed AFM, Kawanna M. Optimum water temperature boosts the growth performance of Nile tilapia (*Oreochromis niloticus*) fry reared in a recycling system. Aquaculture Research. 2008;39(6):670-672.
Available:https://doi.org/10.1111/j.1365-2109.2008.01915.x
26. Rakocy JE, Bailey DS, Shultz RC, Eric S, Thoman ES. Update on tilapia and vegetable production in the UVI aquaponic system. University of the Virgin Islands, USA; 2010.
27. Masser MP, Rakocy J, Losordo TM. Recirculating aquaculture tank production systems management of recirculating systems. South. Reg. Aquac. Cent. 1999;1–12.
28. Knaus U, Palm HW. Effects of the fish species choice on vegetables in aquaponics under spring-summer conditions in northern Germany (Mecklenburg Western Pomerania). Aquaculture. 2017;473:62–73.
29. Rakocy JE. Integrating fish and plant culture. In Aquaculture Production Systems; John Wiley & Sons, Inc.: Oxford, UK; 2012.
30. Pinho SM, Molinari D, de Mello GL, Fitzsimmons KM, Coelho Emerenciano MG. Effluent from a biofloc technology (BFT) tilapia culture on the aquaponics production of different lettuce varieties. Ecol. Eng. 2017;103:146–153.
31. Van Rijn J, Rivera G. Aerobic and anaerobic biofiltration in an aquaculture unit nitrite accumulation as a result of nitrification and denitrification. J. Aquac. Eng. Fish. Res. 1990;9:217–234.
32. Mamatha D, Verma AK, Tiwari VK, Chandrakant MH, Nayak SK, Javed H. Biointegration of Rohu (*Labeo rohita*) Fry and Lemon Grass (*Cymbopogon citratus*) in a Recirculating Aquaponic System. Journal of the Indian Society of Coastal Agricultural Research. 2020;38(2).
33. Wafula AE, Gichana Z, Onchieku J, Orina P, Nyakeya K, Musa S. Biochar-based biofilter media improves water quality in recirculating aquaculture systems. Journal of Crops, Livestock and Pests Management. 2023;1(1):79-90
34. Watson CA, Hill JE. Design criteria for recirculating, marine ornamental production systems. J. Aquac. Eng. Fish. Res. 2006;34(3):157–162.
35. Rakocy JE, Masser MP, Losordo TM. Recirculating aquaculture tank production systems: Aquaponics—integrating fish and plant culture. SRAC publication. 2006;454:1–16.
36. Estim A, Saufie S, Mustafa S. Water quality remediation using aquaponics sub-systems as biological and mechanical filters in aquaculture. Journal of Water Process Engineering. 2019;30:100566.
Available:https://doi.org/10.1016/j.jwpe.2018.02.001
37. Wongkiew S, Hu Z, Chandran K, Lee JW, Khanal SK, Nitrogen transformations in aquaponic systems: A review. Aquac. Eng. 2017;76:9–19.
38. Buzby KM, Lin LS. Scaling aquaponic systems: Balancing plant uptake with fish output. Aquac. Eng. 2014;63:39–44.
39. Jones C, Olson-rutz K, Dinkins C. Nutrient uptake timing by crops, to assist with fertilizing decisions; Montana State University: Bozeman, MT, USA. 2015;8.
40. Endut A, Lananan F, Jusoh A, Cik WNW, Nora'aini A. Aquaponics recirculation system: A sustainable food source for the future water conserves and resources. Malays. J. Appl. Sci. 2016;1:1–12.
41. Wongkiew S, Hu Z, Chandran K, Lee JW, Khanal SK. Nitrogen transformations in aquaponic systems: A review. Aquacultural Engineering. 2017;76:9-19.
Available:https://doi.org/10.1016/j.aquaeng.2017.01.004
42. El-Shafai SA, El-Gohary FA, Nasr FA, van der Steen NP, Gijzen HJ. Chronic ammonia toxicity to duckweed-fed tilapia (*Oreochromis niloticus*). Aquaculture. 2004;232(1-4):117–127.
43. Atle F, Evensen TH, Vollen T, Oiestad V. Effects of chronic ammonia exposure on growth and food conversion efficiency in juvenile spotted wolfish. Aquaculture. 2003;228:215–224.
44. Lemarie G, Dosdat A, Coves D, Dutto G, Gasset E, Person LRJ. Effect of chronic ammonia exposure on growth of European seabass (*Dicentrarchus labrax*) juveniles. Aquaculture. 2004;229:479–491.
45. Sten IS, Trine D, Atle F, Atle M. Effects of chronic ammonia exposure on gonad

growth and survival in green sea urchin *Strongylocentrotus droebachiensis*. Aquaculture. 2004;242:313–320.

46. Stickney RR. Aquaculture: An introduction text. CABI publication, Cambridge, USA. 2005 ;211.

47. Yang T, Kim HJ. Nutrient management regime affects water quality, crop growth, and nitrogen use efficiency of aquaponic systems. Scientia Horticulturae. 2019; 256: 108619.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/114165