Original Research Article

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

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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 potential of chia (*Salvia hispanica*) and lemon grass (*Cymbopogon citratus*) to treat aquaculture wastewater and their impact on fish growth within 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 ($P< 0.05$) 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, such as managing nutrient concentrations to provide plants with optimal concentrations while avoiding 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. MATERIAL AND METHODS

2.1 STUDY SITE

This study was conducted atAqualifefish farm, Kithiniabout 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, andat 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 and set-

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. with three treatments and 3 replicates were used. The first system acted as a control, with no plants in the hydroponic beds; the second system incorporated chia (*Salvia hispanica*) and the third system had lemon grass (*Cymbopogon citratus*) in the hydroponic beds. 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 the output from the fish tanks were collected before pumping to the biofilters; plastic biofilter unit (600 L, 0.75 m) and 3 hydroponic grow beds (1.5×0.5×0.8 m) filled with gravel (Ø 5-15 mm) to anchor the roots and hold plants. The hydroponic grow beds functioned as a biofilter for purifying water from the biofilter and a hydroponic substrate providing growing medium for plants from the constant circulation of water. The system's four 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 was (6 ± 0.24 L/min) and approximately 1.42 ± 0.23 L/min to each hydroponic grow bed. The fish tanks were equipped with porous aeration discs connected to an aeration pump blower (>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.

2.3 Water quality parameters

The culture water within each unit remained unchanged, with daily manual refills compensating 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 (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 biogeochemical 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 wet 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

All collected data including water quality parameters such as temperature, pH, dissolved oxygen (DO), ammonia, nitrite, nitrate and soluble reactive phosphorus (SRP), fish length, weight, plant length and 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. Water quality parameters and fish growth performance across aquaponic treatments were compared using one-way ANOVA. Significant differences ($p < 0.05$) were further analyzed with Tukey's HSD test to identify specific differences. Plant length and weight differences were analysed using a t-test to identify significant variations between treatments. 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]. Similarly, pH values clustered around neutral, ranging from 7.65 to 7.87 (Table 1), suggesting effective buffering capacity within the systems. Dissolved oxygen (DO) was maintained between 4.54 and 6.53 mgL^{-1}, which falls within the range considered optimal for warm water fish such as *O. niloticus* (> 5 mgL^{-1}), plant growth and performance of biofilters [27]. Noticeable variations ($P< 0.05$) in nutrient concentrations between treatments was observed during the 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}) compared to the planted systems (0.04 ± 0.14 mgL^{-1} for *C. citratus* and 0.06 ± 0.05 mgL^{-1} for *S. hispanica*). These findings align with previous studies by [16,17,28], which also observed elevated ammonia levels in control systems without plants. While the observed ammonia levels remained within the acceptable range for *O. niloticus* growth and survival, the presence of plants clearly contributed to more effective ammonia management within the aquaponic systems. The observed 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 [16,29]. 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 incorporation [29].

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)

The removal rates for ammonia, nitrites, and nitrates were similar across the control, *C. citratus*, and *S. hispanica* systems. However, *C. citratus* (55.8%) and *S. hispanica* (55.9%) recorded relatively high ammonia removal rates. The two systems had relatively high ammonia removal rates (around 56%), indicating their efficacy in managing this potentially harmful nitrogenous compound. This highlights their potential role in maintaining water quality suitable for both plants and fish. Plants absorb nutrients through their root, 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. The presence of these bacteria is likely to account for the lower ammonia levels found in plant-integrated systems [14,30]. *C. citratus*'s superior performance in ammonia removal could be attributed to specific physiological or morphological traits that improve nutrient uptake and processing when compared to *S. hispanica*. The plant's root system is more extensive, allowing more beneficial bacteria to colonize and convert ammonia [28]. The mean phosphate 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%). This indicates their superior ability to uptake and utilize phosphorus, a crucial nutrient for plant growth.

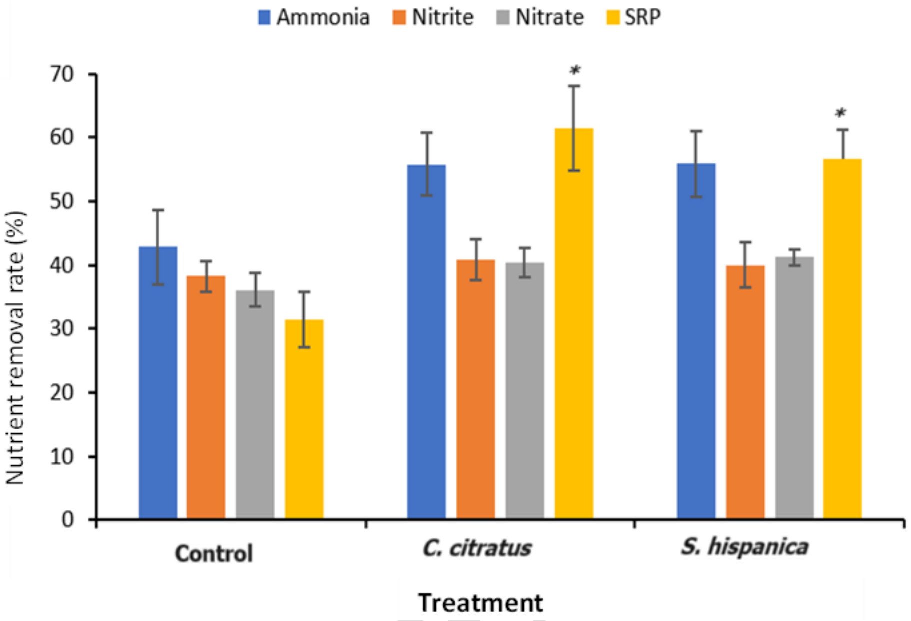

Fig. 1. Nutrient removal rates (ammonia, nitrite, nitrate & soluble reactive phosphorus (SRP)) in the control, *C. citratus* and *S. hispanica* aquaponic systems
*Aquaponics treatment: significant from the control, * $P < 0.05$*

3.2 Fish growth performance

The final weight gain was similar across all treatments (Table 2). However, weight gain, FCR, and specific growth rates varied across treatments. In the *C. citratus* system, the FCR was low (1.7 ± 0.01) and higher (2.1±0.01) in the control aquaponic system ($P<0.05$). 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. 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 feed conversion ratios (FCR) in this study were comparable with those observed by [29] and within the recommended range (1.5-2.0) for *O.niloticus* grown in recirculating systems [31].

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)

Plant growth performance

Figure 2 shows the growth parameters for plant species, including weight and relative growth rates. *Cymbopogon citratus* had a significantly higher (*P* = 0.00) mean weight, (450 ± 9.17 g) twice the weight *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 gd^{-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 [32], who studied the integration of *S. hispanica*, *Brassica rapa*, *Lactuca sativa*, *Beta vulgaris*, *Ocimumbasilicum,Solanum lycopersicum*, and *O. niloticus*. The findings show that plants' ability to utilize nutrients from aquaculture wastewater varies, which 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, herbal plants can effectively reduce aquaculture effluents while improving water quality for fish production.

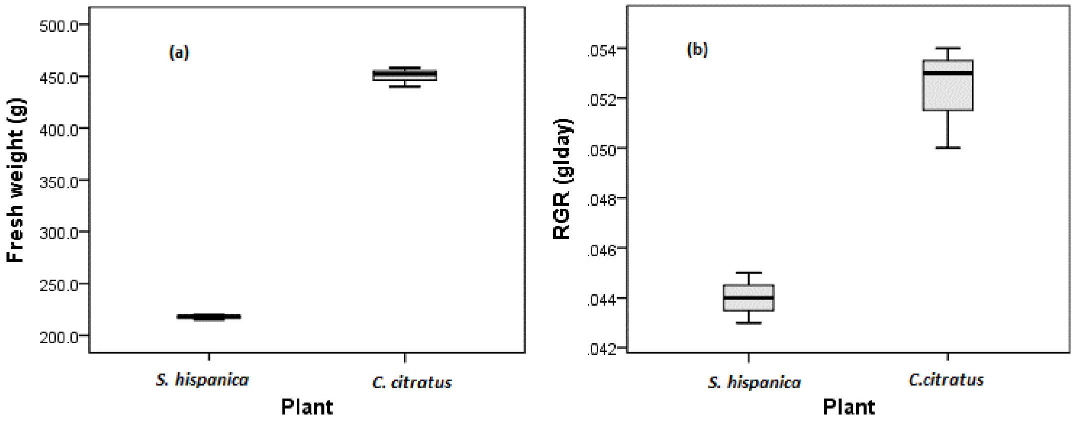

Fig. 2. Box and whisker plots of (a) plant mean weight and (b) relative growth rate (RGR) in the aquaponic system.

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 superior nutrient removal 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*. This could be attributed to higher nutrient removal efficiency of *C. citratus*. Our findings emphasize the importance of plants in maintaining water quality in aquaponic systems. Integrating suitable plant species can significantly reduce harmful ammonia levels, resulting in a healthier environment for fish and promoting overall system stability.

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