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Performance of Nile Tilapia and vegetables Grown in Different Aquaponic Volumes

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Abstract

The objective of this study was to evaluate the performance of Nile tilapia and the lettuce, watercress, and arugula vegetables in a gravel-bed aquaponic system using the aerated fish tank-to-vegetable growing bed volume ratios of 1:1 and 1:2. Each experimental unit consisted of an aquaponic module composed of two containers: one to allocate the vegetables (500-L tank with gravel, measuring 2 m^2) and another to stock fish at the ratios of 1:1 (500-L vegetable:500-L fish tank) and 1:2 (500-L vegetable tank:1000-Lfish tank). The experiment was laid out in a randomized-block design with two treatments (500-L fish tank × 1000-L fish tank) and three blocks (periods). The performance of the Nile tilapia and of the vegetables did not differ significantly in response to the increasing fish tank volume, with the fish and the vegetables exhibiting good performance results in both volume ratios. In conclusion, in aquaponics, the fish tank-to-vegetable tank volume ratios of 1:1 and 1:2 are equally effective for the production of Nile tilapia and the lettuce, watercress and arugula vegetables.

Keywords: lettuce, watercress, *Oreochromis niloticus*, aquiculture systems, arugula

1. Introduction

Technological innovations in aquaculture are important to maximize production and reduce environmental impacts. Aquaponics emerges to attend to these needs, as it associates aquiculture with hydroponics, in which the water from fish production, which is rich in nutrients, is used to irrigate the vegetables (Rakocy, 2012; Trang *et al.*, 2017). In aquaponics, fish receive feed and excrete waste that is used by microorganisms to transform ammonia into nitrite and, later, into nitrate, a form that is absorbable by plants (Rakocy *et al.*, 2006).

Aquaponics is practiced in various models and volumes, which include NFT (Nutrient Film Technique) or pipes, which consists of an aquaponic system formed by structures of PVC tubes placed horizontally, with plants allocated inside the holes in the upper part of the tubes (Somerville *et al.*, 2014); DWC (Deep Water Culture) or floating/raft aquaponic system, which combines the simplicity of handling the harvest and the planting of seedlings, as they are allocated in floating plates with spaced holes (Tokunaga *et al.*, 2015); and MFB (Media-Filled Bed), which is formed by simple structures composed of a tank or water box for fish and a bench with a container with gravel or similar material to accommodate the vegetables, which makes this system the most practical and functional (Maucieri *et al.*, 2018).

Good performance results have been obtained for vegetables and fish, such as tilapia, in gravel aquaponic systems at different stocking densities (Babatunde *et al.*, 2019), and better biomass gain and yield results were achieved as compared with the NFT and raft systems (Lennard and Leonard, 2006).

However, comparative information is lacking regarding the most efficient dimensions for the media-filled bed aquaponic system for the production of Nile tilapia and the lettuce, watercress and arugula vegetables. Thus, appropriate volumes must be defined for Nile tilapia farming to maximize vegetable production performance. The aim of this study was to evaluate the performance of Nile tilapia and the lettuce, watercress and arugula vegetables in a gravel aquaponic system at aerated fish tank-to-vegetable growing bed volume ratios of 1:1 (500-L vegetable tank:500-L fish tank) and 1:2 (500-L vegetable tank:1000-L fish tank).

2. Material and Methods

2.1 Experimental System

The experiment was carried out at the Fish Farming sector at the Federal University of Mato Grosso do Sul, located in Campo Grande, MS, Brazil. All experimental procedures used in the research were approved by the Animal Use Ethics Committee (CEUA) – Federal University of Mato Grosso do Sul (approval no. 889/2017).

The experiment was laid out in a randomized-block design with two treatments (500-L fish tank × 1000-L fish tank) and three blocks, which were used to control the periods variable. The modules performed three water discharges per hour. The experimental unit was the aquaponic module composed of two tanks: one to allocate the vegetables and the gravel (500-L volume tank and with 2-m^2 surface, gravel with a size of 1.5-2 cm, placed at a height of 25-27 cm) and another with aeration to stock fish at the ratios of 1:1 (500-L vegetable tank:500-L fish tank) and 1:2 (500-L vegetable tank:1000-L fish tank).

In aquaponics, a Bell siphon was used to create a flood and drainage system in the vegetable growing bed. The effluent from the fish tank was pumped to the vegetable tank using a 44-W submerged pump (JAD FP-58). The water from the vegetable growing bed returned to the fish tank by gravity through a 32-mm PVC drain tube connected to the Bell siphon (vertical

32-mm PVC tube, 50-mm bell siphon and a 100-mm media-guard). The vegetable tank drained in five minutes and took 14 min to be completely filled, which totaled three renewals per hour. Continuous aeration was provided for each Nile tilapia tank by an aeration system with an electromagnet compressor (160 L/h).

The species used in the test was Nile tilapia (*Oreochromis niloticus*), which was farmed at a density of 4 kg/m^3 that corresponded to 12 fish/m^3. The modules had independent water recirculation. The 500-L gravel tank was used to allocate the vegetables, with 40 seedlings of watercress (*Rorippa nasturtium-aquaticum*) (0.120 kg/m^2), 20 seedlings of crisp lettuce (*Lactuva sativa*) (0.120 kg m^2) and 40 seedlings of arugula (*Eruca sativa*) (0.160 kg/m^2) per unit, which corresponded to 50.0 seedlings/m^2. To stabilize the aquaponic systems, fertilizer urea was used and water previously matured with bacteria and algae was inoculated (Pereira and Mercante, 2005).

2.2 Performance Variables

Biometric measurements were performed at the start and end (40 days) of the experimental period. Before each of these measuring events, the fish were fasted for 24 h and then anesthetized with eugenol at the concentration of 50 mg/L (Vidal *et al.*, 2008). The following performance variables were evaluated in the Nile tilapia: final weight (g); apparent feed conversion {Feed intake in the period, in kg/[(Initial number of fish + Final number of fish)/2]*(Final weight, in kg - Initial weight, in kg)}; survival {[(12-(Final number of fish-Initial number of fish)/12]*100}; daily weight gain [(Final weight, g - Initial weight, in g)/30 days]; final biomass [(Final weight, in g * Final number of fish* 1000 L) in kg] and biomass gain (Final biomass - Initial biomass, in kg). The vegetables were weighed individually and the following weights were recorded: lettuce leaves (g), lettuce roots (g), whole lettuce (g), lettuce biomass (kg), watercress biomass (kg), arugula leaves (g), arugula roots (g), whole arugula (g), arugula biomass (kg) and total vegetable biomass (kg).

2.3 Feeding Management and Water Quality

The fish were fed a commercial extruded feed with a 6- to 8-mm pellet (32% crude protein, 6.5% ether extract, 4% crude fiber, 14% mineral matter and 12% moisture). The feed was supplied to apparent satiety, twice daily, at 08h00 and 17h00.

Water temperature (ºC), dissolved oxygen (mg/L) and pH were measured daily with probes (YSI Professional). Ammonia (NH_3), total ammonia nitrogen (TAN) and nitrite (NO_2^-) were determined twice a week using colorimetric kits (Alfakit). Solids from the remaining feed and feces were siphoned and water lost through evaporation was replaced weekly.

2.4 Analysis

Analysis of variance was performed with effects of treatments and blocks as the sources of variation and fish initial weight as the co-variable. The data were analyzed using the GLM procedure of SAS 9.0 statistical software.

3. Results

The water quality variables were maintained at adequate levels and did not differ (P>0.05) in the different tank volumes of Nile tilapia production in an aquaponic system (Table 1).

Table 1. Physico-chemical characteristics of water from Nile tilapia production in a gravel aquaponic system at aerated fish tank-to-vegetable growing bed volume ratios of 1:1 (500-L vegetable tank:500-L fish tank) and 1:2 (500-L vegetable tank:1000-L fish tank)

Variable	Ratio between tanks		CV (%)(1)	P value
	1:1	1:2		
Temperature (°C)	24.96	25.12	0.33	0.15
pH	7.50	7.52	0.19	0.42
Dissolved oxygen (mg L^{-1})	4.37	4.07	10.82	0.51
Total ammonia nitrogen (mg L^{-1})	0.42	0.45	19.58	0.71
Ammonia (mg L^{-1})	0.02	0.02	18.84	0.42
Nitrite (mg L^{-1})	0.05	0.09	21.54	0.06

(1) Coefficient of variation.

There was no significant difference by Student's T test (P>0.05).

The final weight, weight gain, daily weight gain, final biomass, biomass gain and apparent feed conversion of Nile tilapia did not differ (P>0.05) when they were grown in the tank volumes of 500 L and 1000 L (Table 2). The leaf, root and whole-vegetable weights of lettuce and arugula did not differ (P>0.05) when the fish were grown in 500-L and 1000-L tanks. Likewise, the biomasses of lettuce, watercress and arugula and the total biomass of the vegetables did not differ (P>0.05) when the fish were grown in 500-L and 1000-L tanks (Table 3).

Table 2. Performance variables of Nile tilapia in a gravel aquaponic system at aerated fish tank-to-vegetable growing bed volume ratios of 1:1 (500-L vegetable tank:500-L fish tank) and 1:2 (500-L vegetable tank:1000-L fish tank)

Variable	Ratio between tanks			
	1:1	1:2	CV(%)(1)	P value
Final weight (kg/m^3)	0.436	0.443	2.05	0.68
Apparent feed conversion	1.68	1.50	16.67	0.70
Survival	95.64	96.01	0.66	0.58
Daily weight gain (g/day)	2.55	2.77	11.31	0.67
Final biomass (kg/m^3)	4.71	4.60	1.43	0.43
Biomass gain (kg/m^3)	0.88	0.71	17.27	0.52

(1) Coefficient of variation.

There was no significant difference by Student's T test (P>0.05).

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Table 3. Production performance variables of vegetables grown in a gravel aquaponic system at aerated fish tank-to-vegetable growing bed volume ratios of 1:1 (500-L vegetable tank:500-L fish tank) and 1:2 (500-L vegetable tank:1000-L fish tank)

Variable	Proportion between tanks			
	1:1	1:2	CV (%)(1)	P value
Lettuce leaves (g)	64	90	29.55	0.54
Lettuce roots (g)	16	31	17.50	0.24
Lettuce biomass (kg/m^2)	1.62	1.42	18.87	0.36
Watercress biomass (kg/m^2)	1.30	1.80	15.00	0.35
Arugula leaves (g)	11	20	27.42	0.37
Arugula roots (g)	4	6	26.12	0.45
Arugula biomass (kg/m^2)	0.51	0.64	86.87	0.88
Total biomass (kg/m^2)	3.44	4.88	26.96	0.51

(1) Coefficient of variation.

There was no significant difference by Student's T test (P>0.05)

4. Discussion

The increase in the volume of fish production tanks from 500 L to 1000 (maintaining the fish density and the volume of the vegetable growing bed at 500 L) did not change water quality. The water characteristics were within the range considered adequate for tropical fish (Boyd, 1998).

Increasing the volume of the fish production tanks from 500 to 1000 L while maintaining the fish density (12 fish/m^3 - 4 kg/m^3) and the volume of the vegetable growing bed (500 L) did not improve the performance of the fish, which was possibly due to the maintenance of the water quality and of the fish stocking density. The effect of Nile tilapia density in gravel aquaponic system on performance was demonstrated by Babatunde *et al.* (2019), who found a decrease in final weight (57.5 to 42.0 g), weight gain (43.2 to 34.0 g) and daily weight gain (1.0 to 0.79 g/day) as density was increased from 100 fish/m^3 (5.7 kg/m^3) to 250 fish/m^3 (10.0 kg/m^3). The performance results obtained in the present study are adequate, considering values obtained with Nile tilapia in net-tanks (Moraes *et al.*, 2009) (biomass gain: 0.476 kg; feed conversion: 1.59), in fish ponds (Assano *et al.*, 2011) (daily weight gain: 2.37 g/day; feed conversion: 1.3) and in aquaponics with biofloc technology (BFT) (Lima *et al.*, 2015) (daily weight gain: 2.16 to 2.36 g/day; feed conversion: 1.38 to 1.62).

In addition to the fish density in the fish production tank, the type of vegetable used in aquaponics interferes with the performance of Nile tilapia when produced in an NFT aquaponic system (Effendi *et al.*, 2017). This is due to the efficiency of the plant to absorb the nitrogen compounds produced by fish. Thus, it can be inferred that, in the present study, the tank management and the vegetable types and densities were adequate to provide water quality for the fish to develop properly.

It is noteworthy that the increase in the volume of the tanks where the fish were produced did not improve the performance of lettuce, watercress or arugula, whether in the leaves, roots, whole vegetable or final biomass. This result indicates that the availability of nutrients in the fish tank volumes of 500 and 1000 L was enough for the vegetables growth. In this respect, perhaps, a larger volume (>500 L) in the vegetable growing beds associated with a larger volume in the fish production tanks (1000 L) could increase the final biomass of the vegetables without impairing individual performance, as it would increase the amount of substrate to make nutrients available to the plants.

The performance obtained for whole lettuce in the present study can be deemed satisfactory, considering that Sace and Fitzsimmons (2013) used NFT aquaponics and found more than the double the weight in the period of 108 days of experiment with lettuce. In their experiment, lettuce showed a lower whole-vegetable weight (75.5 g) than that found in the present study (80 and 121 g). The authors also used Nile tilapia, but in 250-L production tanks. In addition to the water volume in the vegetable growing bed (which did not interfere with the performance of the vegetables, in the present experiment), the weight and biomass of vegetables depend on other factors, such as the type of substrate used in the aquaponic tanks (Rakocy *et al.*, 2006), climatic conditions (Love *et al.*, 2015), type of aquatic organism species produced in aquaponics (Sace and Fitzsimmons, 2013), quantity and quality of feed (Rakocy, 2012), aquaponics type (Carneiro *et al.*, 2015) and plant variety (Pinho *et al.*, 2017).

It is important to highlight the great efficiency of the aquaponics system in the production of vegetables as compared with other fish production systems. Pinho *et al.* (2017) found a larger biomass of the lettuce varieties red (0.56 kg/m^2), butter (1.94 kg/m^2) and crispy (1.36 kg/m^2) in a raft aquaponics system (with BFT) in relation to the clear water system (red 0.28 kg/m^2; butter: 1.53 kg/m^2; and crispy: 1.04 kg/m^2) in 500-L fish production tanks during 21 days. Although the authors did not work with the crisp lettuce variety (the variety used in the present study), there was a great difference in the performance of the different lettuce varieties, with the red variety showing inferior results than the crisp lettuce in the present study.

The larger biomass of lettuce and watercress indicate that these vegetables are more suitable for production in aquaponics in relation to arugula in the tank volumes, fish species and fish density used. Similar results were observed by Lennard and Ward (2019), who reported a whole-arugula weight of 10.7 g with a growing period of 42 days in an NFT aquaponic system, which is close to the 14 g obtained in the current study. These authors showed better performance of the lettuce varieties (seven varieties) as compared with arugula, suggesting that the latter is less adapted to aquaponics than other vegetables, with values almost three times lower than when produced in hydroponics in the same period (31 g), which the present findings corroborate. Although there is a difference between the varieties, lettuce showed results close to those obtained in aquaponics by Pinho *et al.* (2017). Likewise, watercress also exhibited values close to those obtained in other studies with raft aquaponics, e.g. Nhan *et al.* (2019) at the density of 180 plants/m^2 (final biomass of 0.460 kg of watercress/m^2).

It should be noted that although there was no significant difference in the performance of the vegetables, higher mean values (non-significant) were found for the three vegetables and total vegetable biomass when the larger tank volume was used for fish production (1000 L) as compared with the lower volume (500 L). This indicates that the increase in the volume of production tanks for these vegetables might also represent an increase in their own performance. Other studies evaluating different ratios and volumes of vegetable production tanks are warranted to corroborate this hypothesis.

5. Conclusion

The aerated fish tank-to-vegetable growing bed volume ratios of 1:1 (500 L:500 L) and 1:2 (500 L:1000 L) are equally effective for the performance of Nile tilapia and of the lettuce, watercress and arugula vegetables.

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