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Research Article

Effect of three productive stages of tilapia (*Oreochromis niloticus*) under hyper-intensive recirculation aquaculture system on the growth of tomato (*Solanum lycopersicum*)

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ABSTRACT. In this research, the effect of different productive stages of tilapia (*Oreochromis niloticus*) in a hyper-intensive aquaculture system on the growth of tomatoes was evaluated. Fish were cultivated in a final density of 80 kg m^3 considering three development stages (an average of fingerling of 1.487 g, juvenile of 62 g, and adult of 203.75 g, respectively). The quality of water was measured by determining temperature, pH, electric conductivity, and dissolved oxygen. Biometric data were registered throughout the growth of fish and tomatoes. Results showed that the survival, growth, and health of fish are not affected by the hyper density of culture; as well as the quality water was maintained under acceptable conditions for the development of organisms. Besides, it was obtained that the early productive stages (fingerlings and juveniles) gave the best results for tomato growth. These results suggest using the wastewater from fingerlings and juveniles of a hyper intensive recirculation aquaculture system to produce hydroponic tomato; to achieve sustainable production systems with maximum use of the resources.

Keywords: *Oreochromis niloticus*; hyper-intensive; productive stages; recirculation aquaponics system; wastewater; hydroponic tomato; aquaculture

INTRODUCTION

There is a great demand for energy, food, and water caused by population increase, which directly impacts environmental problems and food shortages, among others (FAO 2018). Due to these food shortages, in recent years, new methods and technologies have been developed for sustainable food production systems that reinforce actions to minimize water scarcity and support sustainable intensification of agriculture through the efficient use of resources (FAO 2014). However, there is a lack of knowledge about directing further activities and developing technologies as potential solutions for loss of soil fertility and biodiversity, scarcity of resources, and shortage of drinking water (Junge et al. 2017). One of the production systems considered a sustainable technology for maximizing water and nutrients to obtain two commercial crops, mitigating damage to the environment, is aquaponics.

Aquaponics is a system that integrates aquaculture and hydroponics, with dual production of fish and plants using the water from the fish tanks for plant growth (Yavuzcan & Beckcan 2017). Simultaneous fish and plant production are possible since the system feeding requirements for fish growth are very similar to the feeding requirements for growing plants (Ebeling et al. 2006). According to this author, recirculation systems are designed to cultivate large quantities of fish and plants in small volumes of water due to their capacity for treatment and reuse.

A wide variety of combinations between fish and plants have been studied (Savidov et al. 2007, Tyson et al. 2008, Knaus & Palm 2017); however, there have been no reports evaluating different productive stages of fish on a particular vegetable crop. On the other hand,

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the tomato is one of the most studied plants in aquaponic; Savidov et al. (2007) compared the relative growth rate of tomato under aquaponics and hydroponic systems. Klanian (2018) evaluated the potential of tomato plants to efficiently use the nitrogen (N) of an aquaponic recirculation system. Knaus & Palm (2017) evaluated the effect of juvenile tilapia on tomato growth. Yavuzcan & Beckcan (2017) reported the results of the production of Nile tilapia (*Oreochromis niloticus*) and tomato (*Solanum lycopersicum*) in the classical aquaponics system with different fish density. The above, to mention some of the studies carried out in aquaponics systems between tilapia and tomato.

Studies have focused on tilapia culture with low densities that do not have the necessary nutrients for the vegetable crops, and therefore they have had to be supplemented with external nutrients for production, and the best stage of fish production for this type of integral system is unknown. For this, it is necessary to know the best production stage that provides the necessary nutrients for tomato production in an aquaponics system that avoids the supplementation of agents external to the system to achieve a sustainable system. Thus, the present study was carried out to determine the best production stage of *O. niloticus* in a hyper-intensive aquiculture system to grow hydroponic tomato (*S. lycopersicum*).

MATERIALS AND METHODS

System design

Three integrated recirculating aquaponic systems were constructed (continuous recirculation between aquaculture and hydroponic unit) to produce *O. niloticus* and *S. lycopersicum* (Fig. 1). In order to provide uniform environmental conditions for the culture, the system's design was located inside a polyethylene greenhouse of 720 m^2 (16×45 m). Three treatments were realized considering three productive stages of fish corresponding to fingerlings, juveniles, and adults, under a culture density of 80 kg m^{-3} of fish (to harvest) and 12 plants m^{-2} of tomato; a hydroponic system was used as a control to compare de vegetable growth of the tomato plant in a system with ideal growing conditions and the treatments with irrigation from fish wastewater.

Each system consisted of a circular polypropylene tank with a maximum capacity of 1 m^3. Recirculation occurred with 345 W submersible pump, Truper brand, for 108 L min^{-1}. For mechanical and biological filtration, a commercial filter of brand BOYU EFU-13500 Pond Filter with UV light, of 115 V, with a capacity of 8,000 to 15,000 L h^{-1}, was used, a submersible water heater of 400 W was activated to control the temperature for periods of one hour with breaks of one hour only at night to maintain the temperature around 28°C in the hours of lowest temperature.

Two plant boxes of 7×0.4 m were placed for the hydroponic crop for each treatment; every plant box contained 30 plants in coconut fiber. The water was recirculated continuously between the fish tank and growth bed in aquaponics. The conduction of water to vegetable culture took place with the same aquaculture recirculation pump; once a day, water was diverted to a reservoir with a capacity of 70 L, which contained the water that was sent to the plants three times a day (09:00, 13:00 and 16:00 h). Water was transported with 60 W pumps at the indicated times, which were activated by timers. A quantity of 1.5 L of water per plant per day was provided, and no micro and macronutrients were added. Finally, water flows down to the fish tank to complete the recirculating system (Fig. 1).

Fish and tomato culture conditions

The total amount of water for each aquaculture system was 250 L. The tilapia culture consists of 420 fingerlings, 140 juveniles, and 60 adults, with an average body weight of 1.487, 62, and 203.75 g, respectively. Fish were fed three times a day with balanced commercial food according to their stage at approxi-mately 10% (fingerlings), 5% (juveniles), and 3% (adults) of body weight per day. A temperature of 28°C and an oxygenation range of 4-6 mg L^{-1} of O_2 was maintained. No water exchange was conducted during the study period except for replenishing evapotranspiration losses.

The culture of tomatoes consists of 60 plants per treatment. Shade cloth (50%) was installed over the grow bed to prevent excessive sun exposure to the plants. Plants seeds were germinated; after two weeks, healthy plant seedlings were transplanted to the grow bed at a plant density of 12 plants m^{-2}. The plant was not supplemented with any nutrient; they were watered only with the water of the fish system without additions. The hydroponic control system was supplemented with Steiner nutrient solution and pH was stabilized with citric acid.

In order to monitor physical water quality, dissolved oxygen, conductivity, pH, and temperature were measured daily during the experiment in fish tanks and hydroponics reservoir; this measurement was realized with a multiparameter instrument (Hach series HQ40d).

Chemical determinations were carried out in three phases to know the behavior of different forms of nitro-

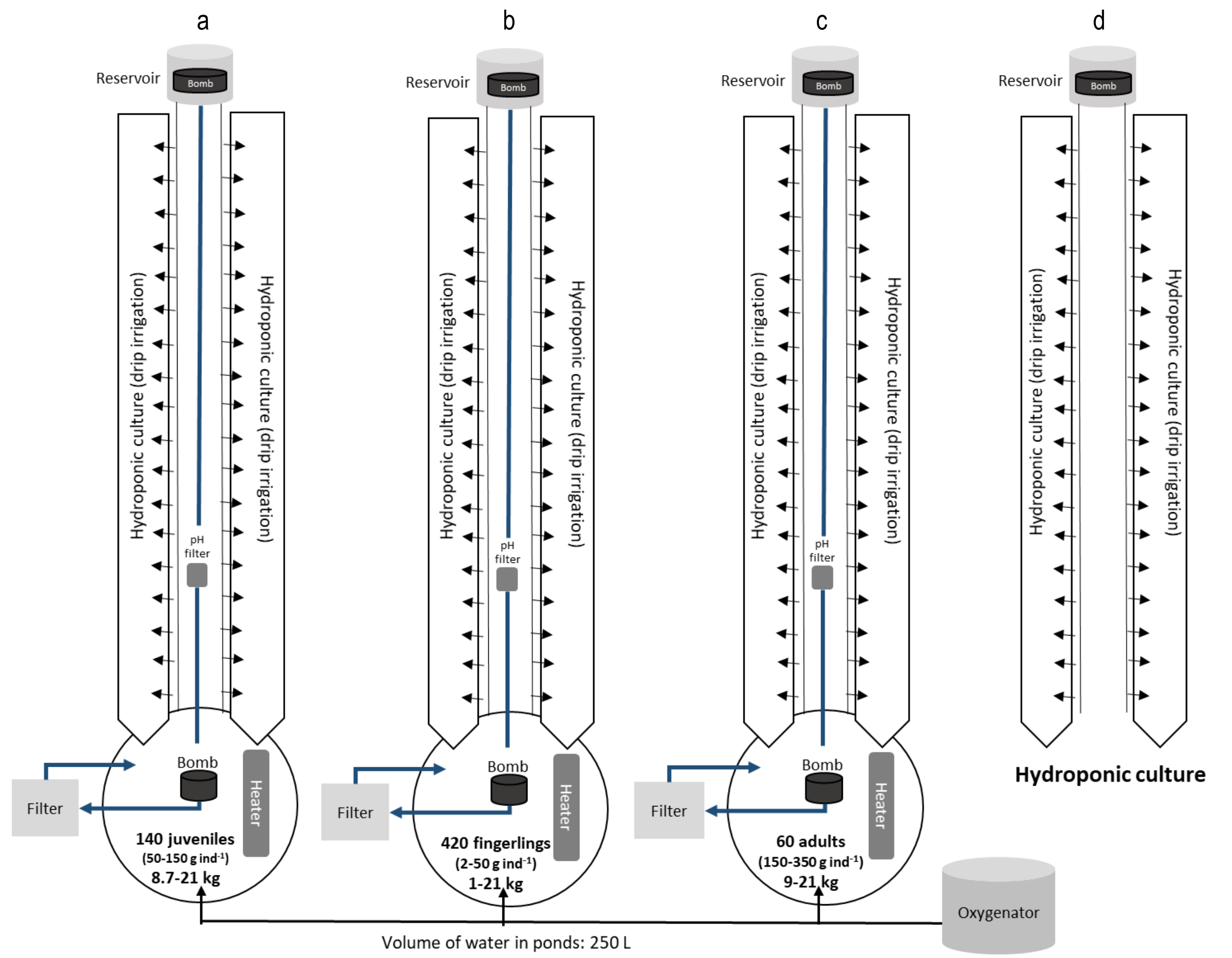

Figure 1. Schematic representation of the system: aquaponic recirculation with a) tilapia juveniles, b) tilapia fingerlings and c) tilapia adults, and control culture with d) hydroponic system with nutrition.

gen present in water: ammonia (NH_3-N), nitrates (NO_3^-), and nitrites (NO_2^-). Samples were taken weekly until all experiment periods. Two hundred fifty milliliters of water sample was taken manually from each tank to carry out determinations. Analyses were carried out immediately after the collection of the sample. Ammonia (NH_3-N) concentration was determined according to HACH method 8038 for DR6000 spectrophotometer called Nessler method with an interval of 0.02-2.50 mg L^{-1} NH_3-N. Nitrite concentration NO_2^- was determined using HACH method 8057 for DR6000 spectrophotometer called diazotization method with an interval of 0.002-0.300 mg L^{-1} NO_2^-. Nitrate concentration NO_3^- was determined according to HACH method 8039 for DR6000 spectrophotometer called cadmium reduction method with an interval of 0.3-30 mg L^{-1} NO_3^-.

Growth performance

The following parameters were used to evaluate tilapia growth performance according to Kumar & Garg (1995):

$$\text{Body weight gain (WG)} = 100\,(W_1 - W_0) \quad (1)$$

$$\text{Body weight gain (WG)} = \frac{(W_1 - W_0)}{t} \quad (2)$$

$$\text{Specific growth rate (SGR)} = \frac{(\ln W_1 - \ln W_0) \times 100}{t} \quad (3)$$

$$\text{Survival rate (\%)(SR)} = \frac{Ni \times 100}{No} \quad (4)$$

where W_1: final wet weight, W_0: initial wet weight, t: time interval in days, Ni: number of fishes at the end, N_0: number of fishes initially stocked. Besides, total mortality and survival for each treatment were obtained at the end of the experiment.

Length-weight relationship and Fulton's condition factor

Length-weight relationships are used to estimate the condition factor, which helps to know the fatness or well-being of fishes (Rodriguez et al. 2017). An equation ($W = a L^b$) is used to estimate the relationship between weight (g) and length (cm), the above mentioned can be transformed to:

$$\log(W) = \log(a) + b\log(L)$$

When this formula is applied, b may not deviate from the ideal value of 3.0, representing an isometric growth; on the other side, if b is less than 3.0, fish is becoming slimmer with increasing length, and growth will be negative allometric. In the other case, when b is greater than 3.0, the fish is becoming heavier, showing positive allometric growth and reflecting optimum condition depending on the kind of fish feed; this is related to the content of protein (Jisr et al. 2018). In order to complement the information about the nutritional status of fish, the estimation of the condition of the organisms was carried out through Fulton's condition factor (K) (Fulton 1904), which indicates a reliable physiological index of the growth and health status of fish, calculated through the following equation:

$$K = (P \times L^{-3}) \times 100$$

where P is wet body weight in grams, and L is the length in cm. Subsequently, a simple ANOVA test was applied to determine the variation in time of K per treatment and the relationship between the condition index and critical weight. Fulton's condition factor, if the value is >1, should be regarded as an indicator for good growth and health.

Statistical analysis

Non-parametric Kruskal-Wallis test was done to compare means between treatments. Significant differences ($P < 0.05$) between sampling points were evaluated by one-way ANOVA using Statgraphics software (Stat Point Inc. 2006).

RESULTS

Water quality control

The registry of the temperature in all treatments remained between 23.61 to 31.2°C (mean ± standard deviation = 26.61 ± 1.82; n = 189), generally, which was controlled with water heaters (Fig. 2). It was possible to increase the temperature of water common in the study site to provide optimal conditions for the development of the fish. The above, compared to what was reported by García-Trejo et al. (2016), recorded an average temperature of 24.68 ± 3.0°C at the same study site.

pH is one of the crucial factors in aquaponics; the importance of maintaining an adequate pH in the system lies in the fact that the concentration of hydrogen ions (H^+) in water could affect the survival and growth of the organisms (White et al. 2013). In this study, a pH range between 7.64 to 8.31 (7.55 ± 0.57; n = 189) was recorded (Fig. 3). The concentration of dissolved oxygen was maintained between 4.1 to 7.51 mg L^{-1} (5.55 ± 0.62; n = 189) to avoid high mortality rates (Fig. 4).

In the present study, there was a fluctuation in conductivity between 0.46 to 1.03 S m^{-1} (0.69 ± 0.11; n = 190). The trend was the same between treatments (Fig. 5). The control vegetable crop had significant differences with respect to the pH and conductivity (6.79 ± 0.36 and 2.60 ± 0.29) of the irrigation water; the above, due to the control that was had with the addition of chemical fertilizers.

Concerning the different forms of nitrogen present in culture water, which was used for direct irrigation without any treatment, to the vegetable culture, the same tendency was presented for ammonium, nitrites, and nitrates. In this respect, the highest and constant values were for the hydroponic culture control, which was supplied with water with nutritive solution (10.01 ± 1.0, 29.77 ± 2.19, and 442.79 ± 16.91, for NH_3^-N, NO_2^- and NO_3^-, respectively). On the other hand, the lowest values were for treatment with adult tilapia, presenting significant differences concerning the rest of the treatments for the three nitrogenous forms (0.90 ± 0.45, 1.28 ± 0.99, and 13.73 ± 15.28, for NH_3^-N, NO_2^- and NO_3^-, respectively). Besides, there were no significant differences between the tilapia rearing and juvenile treatments (Fig. 6).

Growth performance

The growth performance parameters of fingerling, juvenile, and adult tilapia in a hyper-intensive aqua-ponic culture is shown (Table 1). Survival values greater than 90% are recorded (93.81% for fingerlings, 94.29% for juveniles, and 91.67% for adults). Regarding the specific growth rate (SGR), the values obtained were within expectation (Fig. 7), the highest values were for fingerlings (3.01), followed by juveniles (1.40), and the lowest SGR was for adults (0.65).

Length-weight relationship and Fulton's condition factor

Values obtained in a length-weight relationship from b for three productive stages during this experiment tended to an isometric growth (Fig. 8) (between 2.85 to

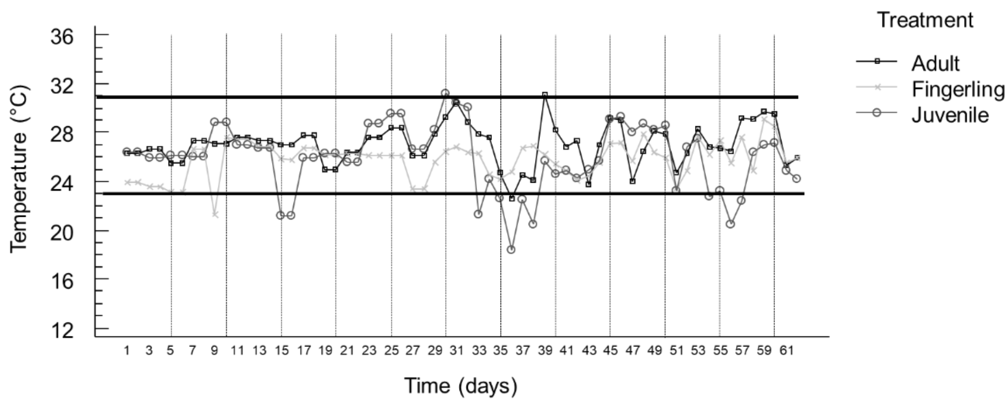

Figure 2. Water temperature behavior in a recirculating aquaponic system in three productive stages of fish.

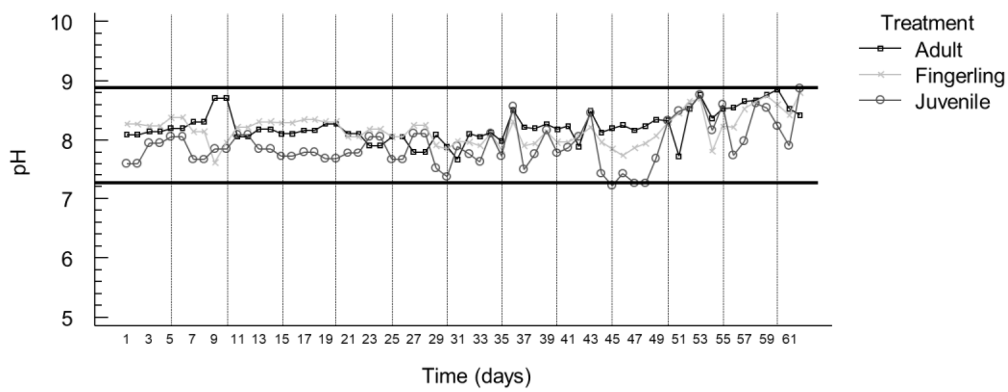

Figure 3. pH behavior in the water of a recirculating aquaponic system in three productive stages of fish.

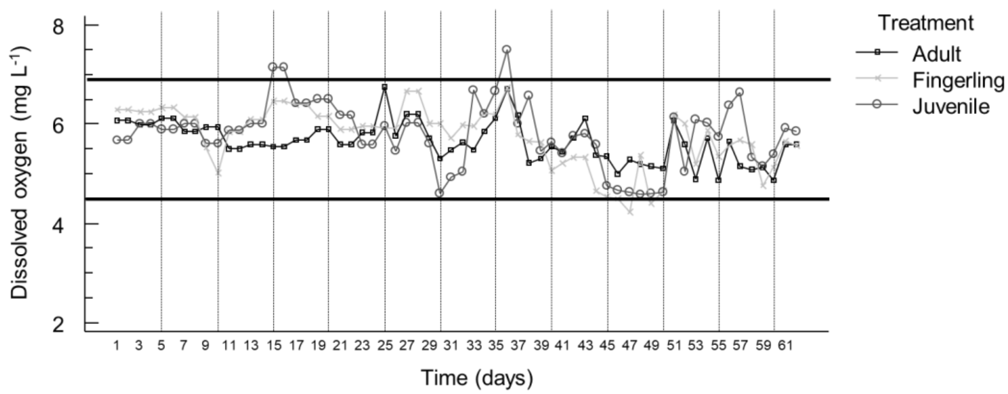

Figure 4. Dissolved oxygen in the water of a recirculating aquaponic system in three productive stages of fish.

3.25), considering that isometric growing species are the ones who fluctuate within the values $b = 2.5$ and $b = 3.5$ (Froese 2006). Regarding Fulton's condition factor (Fig. 9), K-value was greater than 1 for three treatments, which indicates a good state of growth and health of the fish. However, there were significant differences ($P < 0.05$) between fingerlings, who presented the lowest value (1.61 ± 0.10) for juveniles and adults (1.80 ± 0.16 and 1.82 ± 0.14).

Tomato (*Solanum lycopersicum*) growth

Regarding the tomato, a germination percentage of 68, 83, 80, and 81 were obtained for fingerlings, juveniles, adults, and hydroponic culture. There were significant differences ($P < 0.05$) in the development of hydroponic culture with the three treatments of the aquaponic culture (with a final average height of 125.78 ± 27.77 cm in the control compared to 94.50 ± 26.29 cm of the best value of the aquaponics cultures). The best development of aquaponic cultures occurred in

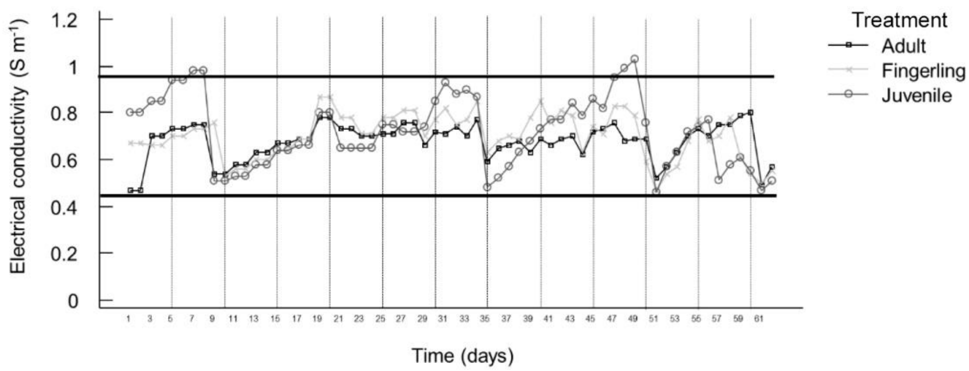

Figure 5. Conductivity in the water of a recirculating aquaponic system in three productive stages of fish.

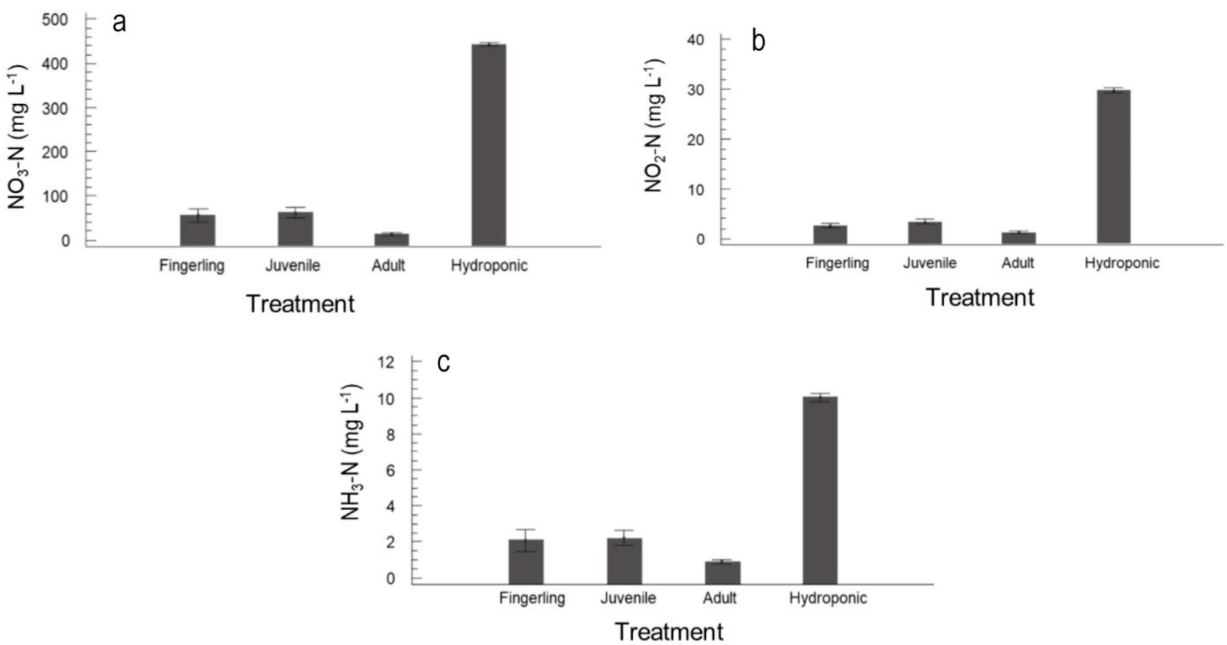

Figure 6. Ammonia, nitrates, and nitrites present in water culture for three productive stages of tilapia: a) nitrates, b) nitrites and c) ammonia.

treatment with residual fingerling water; there are no significant differences with the residual water of juvenile tilapia (Fig. 10). Both treatments had significant differences with adult tilapia wastewater, where there was no flowering or fruiting. The survival rate had the same behavior as growth. The highest value was for tomatoes fed with fingerling water (98.33%), followed by vegetable cultivation with water of juvenile tilapia (93.33%), and finally, a lower survival rate was in culture irrigated with residual water from the adult tilapia (91.66%) (Table 2).

DISCUSSION

Water quality control

Temperature, pH, and dissolved oxygen in aquaculture are conditions that can affect the development of the fish and compromise the quality of water. For plant cultivation, the same factors are important for its development, as well as conductivity. That is why monitoring these physical factors in the fish's water, which feeds the hydroponic culture, was carried out. Hence, it can be observed that temperature in all treatments of the present study was maintained between 24-30°C, which corresponds to the optimum temperature range for good development of tilapia, according to Ebeling et al. (2006). On the other hand, a pH range of 7 to 9 was recorded, whose values are acceptable for tilapia *Oreochromis niloticus* culture (El-Shrerif & El-Feky 2009); however, it is not suitable for the growth of tomato cultivation (Bugbee 2003).

Nevertheless, it was decided not to carry out pH adjustments in the system to evaluate the development

Table 1. Growth performance parameters for three productive stages of *Oreochromis niloticus* in a hyper-intensive aquaponics system.

Performance parameters	Treatment		
	Fingerling	Juvenile	Adult
Initial number (n)	420	140	60
Final mean number (n)	394	132	55
Initial total weight (g)	1528.80 ± 57.9	8680.00 ± 94.7	11,779.20 ± 24.5
Final total weight (g)	17,040.50 ± 350.6	26,554.44 ± 403.14	19,745.00 ± 401.81
Initial individual mean weight (g)	3.64 ± 1.38	62.00 ± 6.77	196.32 ± 40.85
Final individual mean weight (g)	43.25 ± 9.04	201.17 ± 30.41	359.00 ± 74.21
Weight gain (g)	15,511.70	17,874.44	7965.80
Weight gain (%)	1014.63	205.93	67.63
Specific growth rate (% d^{-1})	3.01	1.40	0.65
Survival rate (%)	93.81	94.29	91.67
Feed conversion ratio (FCR)	1.38	1.62	1.44

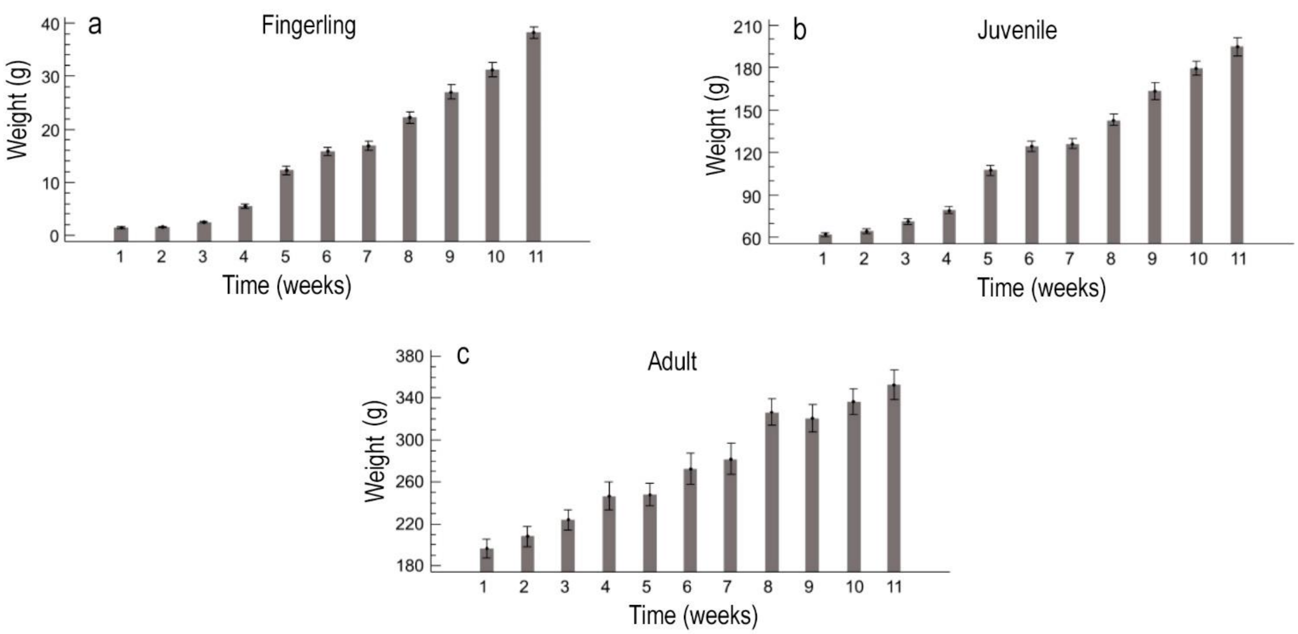

Figure 7. Graphs of growth of tilapia *Oreochromis niloticus* in three productive stages in a hyper-intensive aquaponic system: a) tilapia fingerling, b) tilapia juvenile and c) tilapia adult.

of both cultivated species without the addition of external agents, except for the hydroponic control system, whose pH was controlled as mentioned in the methods section. Additionally, dissolved oxygen is one of the most important factors for fish survival, feed intake, growth, and metabolism (Tran-Duy et al. 2012), especially in a hyper-intensive aquaculture system; thus, tilapia in this study was never compromised by the absence of oxygen. Lastly, conductivity presented low values according to the requirements of the vegetable crops and when compared with control system; however, it coincided with that reported by (Diem et al. 2017) with values between 0.3 and 0.55 S m^{-1}.

As aquaponics is an integrated system that links aquaculture production systems with hydroponics with the use of water and the nutrients present in it (Hu et al. 2015), it was considered important to evaluate the behavior of one of the elements with greater importance for animal and vegetable crops, the nitrogen. In aquaponic systems, nitrogen is required to meet the nutritional requirements of fish and plants (Schmautz et al. 2021); however, it can be toxic, especially to fish at high concentrations. Taking as a reference what was reported by Timmons et al. (2002) as tolerant reference concentrations for the development of tilapia (NH_3^-N <1 mg L^{-1}, NO_2 <1 mg L^{-1}, NO_3 0-400 mg L^{-1}, and

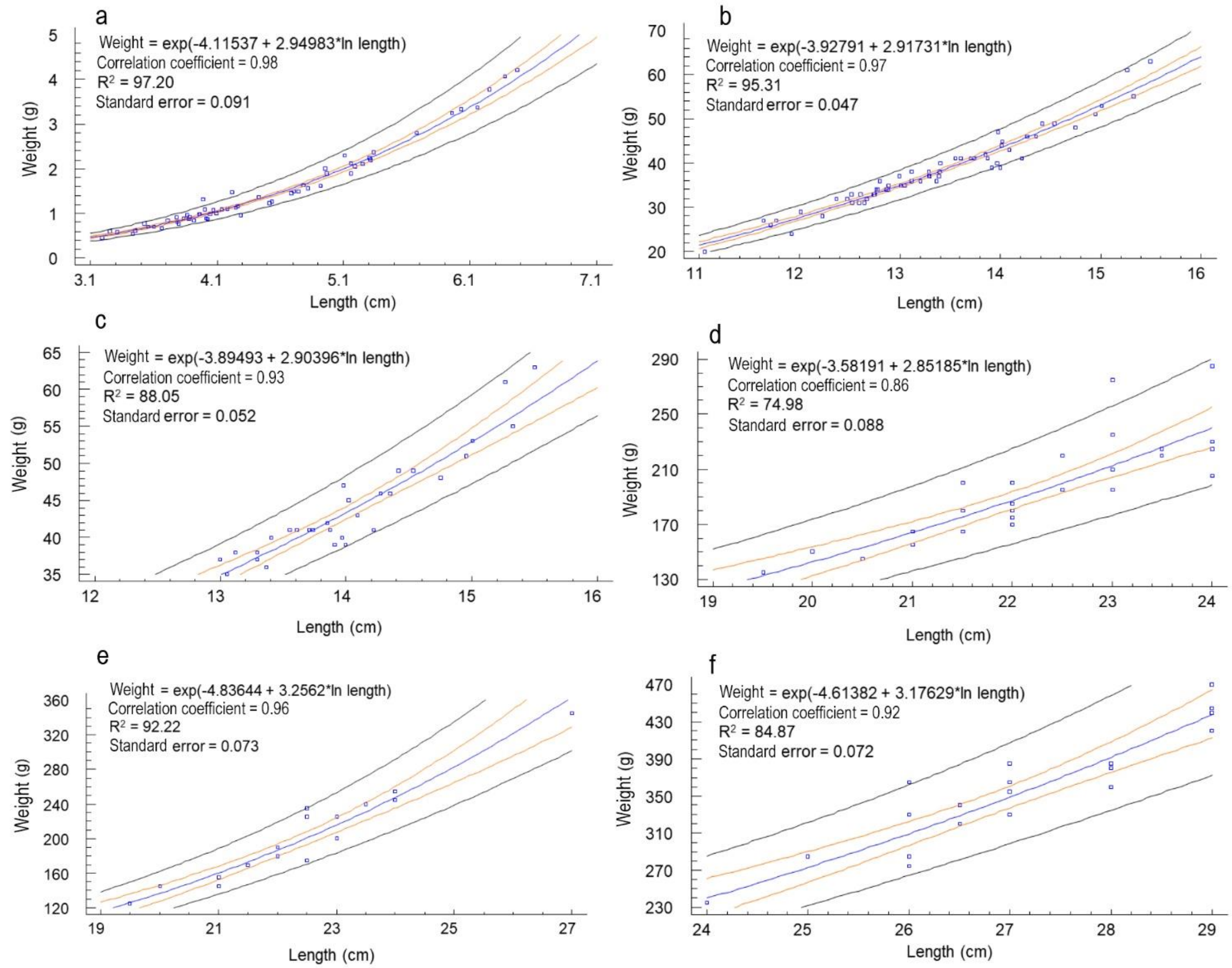

Figure 8. Relation of length-weight relationship at the beginning and end of the experiment of *Oreochromis niloticus* in three productive stages: a) fingerling initial, b) fingerling final, c) juvenile initial d) juvenile final, e) adult initial and f) adult final.

phosphorus 0.01-3 mg L^{-1}), only nitrates were within the established range; unlike nitrites and ammonium, which exceeded these reference values. Despite this, no effect was observed on the growth and survival of fish, so it was decided to continue with the density of fish originally established, providing a greater amount of nutrients to the plant culture.

Tilapia growth performance

All values obtained were similar to those obtained by other researchers with tilapia of similar sizes but lower stocking densities. For fingerlings, other authors obtained lower SGR than that obtained in the present study, such as (Yustiati et al. 2019), who reported an SGR of 2.7% in tilapia with an initial average weight of 8.75 g. On the other hand, Rahmat et al. (2019) showed an SGR of 1.31% of tilapia with an average initial weight of 9 g. For juveniles, the SGR was similar to those obtained by other authors like Yong et al. (2018), who reported an SGR of 1.60 for juveniles of 37 g, and Bowyer et al. (2020) with an SGR of 2.2. They work with a density between 20 and 30 kg m^{-3} compared with 80 kg m^{-3} of the present study. On the other side, the SGR of adults of tilapia (0.65%) coincided with Obirikorang et al. (2019), who obtained a value of 0.65% of SGR in 78 g tilapia.

Length-weight relationship and Fulton's condition factor

In order to know the health status of the fish in the system at the beginning and the end of the experiment, a condition factor and a length-weight relationship were carried out, which provided indirect information on growth, maturity, reproduction, nutrition, and the health status of the populations (Cifuentes et al. 2012). In general, all treatments of the present study growth

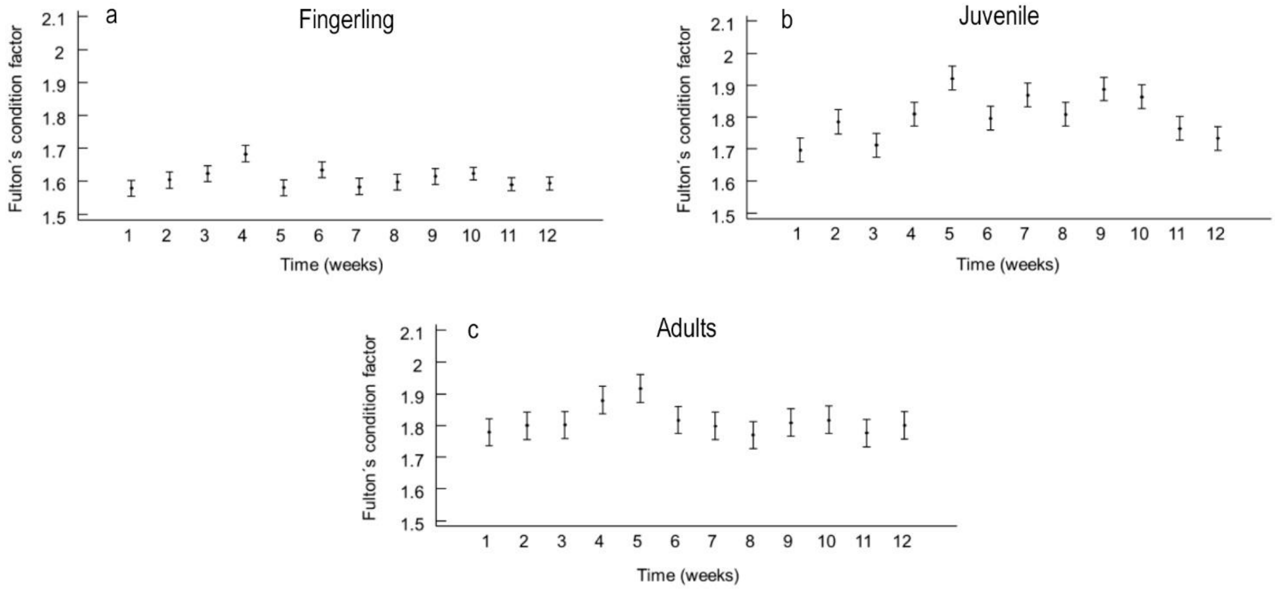

Figure 9. Fulton's condition factor of the experiment of *Oreochromis niloticus* in three productive stages: a) fingerling, b) juvenile, and c) adult.

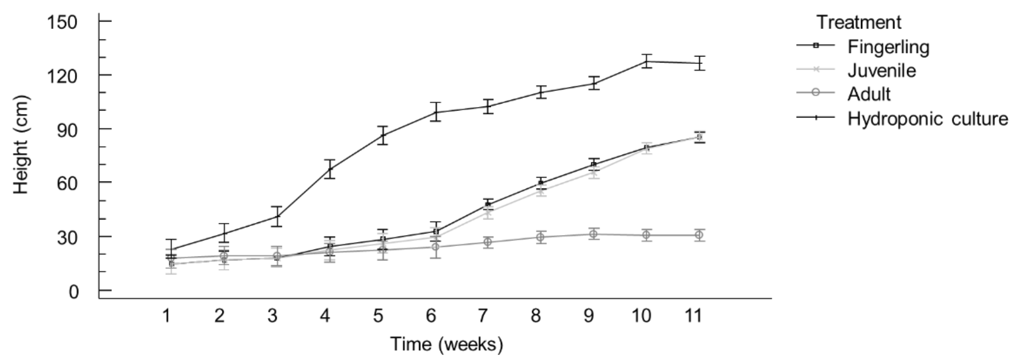

Figure 10. Graph of plant growth (*Solanum lycopersicum*) in aquaponic culture with residual water of fingerlings, juveniles, adults of tilapia *Oreochromis niloticus*, and hydroponic culture as a reference.

were isometric, indicating a good physiological state. The importance of analyzing this relationship at the beginning and end of the experiment is because we need to ensure that the fish entered the system in good health and that hyper density and recirculation in the aquaponic system are not affecting the good development of the product. Studies of length-weight relationship carried out with the same species and in RAS reported values of 3.168 (Gullian-Klanian & Arámburu-Adame 2013), 3.1 (Anani & Nunoo 2016), 3.3 (Ondhoro et al. 2019). Therefore, it can see that fish were in a good physiological state throughout the experiment.

On the other hand, the estimation of Fulton's condition factor was carried out, which is a good parameter that shows the well-being of fish in their natural habitat or aquaculture (Tesfahun 2018) because it is considered as a measurement of biological and ecological factors for their feeding conditions (Nehemia et al. 2012). The value obtained for all treatments was greater than 1, which is considered an indicator of good growth and health, as well as it was less than 2, indicating that the fish are not exposed to obesogenic elements and are not eating excessively (Adeogun et al. 2016). Pauker & Rogers (2004) mention that values greater than 1 in K is related to high energy content, food availability, and adequate environmental conditions. According to this, it is observed that the productive stages that were in the best conditions were juveniles and adults as they obtained a higher condition factor which can be explained because the condition factor is influenced, among other things, by physiological conditions, age, food supply and ammonium concentration (Froese 2006), factors that

Table 2. Growth performance parameters for tomato (*Solanum lycopersicum*) watered with wastewater of three productive stages of tilapia (*Oreochromis niloticus*) in a hyper-intensive aquaponics system.

Performance parameters	Treatment			
	Fingerling	Juvenile	Adult	Hydroponic culture
Initial number (n)	60	60	60	40
Final mean number (n)	59	56	55	40
Germination (%)	68	83	80	81
Average initial height (cm)	14.43 ± 2.05	14.61 ± 1.76	17.68 ± 2.16	23 ± 3.97
Average final height (cm)	94.50 ± 26.29	94.31 ± 30.34	30.04 ± 10.81	125.78 ± 27.77

varied in the treatments. Fingerlings were the ones with the highest concentration of ammonia.

Several authors have estimated Fulton's condition factor, but much of the reported data for K is in its natural environment, showing values between 0.5 to 3.5 (Senait 2015, Yun-Ru et al. 2017, Shija 2020). However, in natural environments, there are a large number of environmental variations that can affect the well-being of organisms. In aquaculture, where conditions are more controlled and homogeneous, lower K condition factors have been reported, as reported in Yucatan farms by Paredes-Trujillo et al. (2021) for fishes of 230.08 ± 127.68 g (K = 0.60 ± 0.14) and fish of 101.62 ± 104.70 (K = 0.12 ± 0.05). Also, similar values to the results of the present study, such as the case of Ferreira et al. (2019), who compared intensive crops (initial 9.68 kg m^{-3} and final 55 kg m^{-3}) with semi-intensive crops (initial 0.058 kg m^{-3} and final 5 kg m^{-3}). In the study by Ferreira et al. (2019) they showed that there are no significant differences in K between the different cultivation densities with values between 1.8 and 2.2 during the entire duration of the experiment. The present study was carried out under conditions of much higher culture density, compared to that reported by other authors, and with a condition factor that indicates a good development of the organisms, so it is assumed that the density is not drastically affecting their well-being.

Tomato (*Solanum lycopersicum*) growth

The best development occurred in the hydroponic culture due to the special nutritive solution for the good development of this crop and the pH adjustment made to the water fed the crop. Concerning aquaponic systems, the highest growth treatments without significant differences were fingerlings and juveniles, reaching a height of 86.18 and 85.58 cm, respectively. Treatment with adults did not have positive results since the growth was very poor (height of 30.45 cm), and there was no flowering. Other authors have carried out similar studies (Roosta & Hamidpour 2011, Wortman 2015, Knaus & Palm 2017, Yang & Kim 2020), who have worked with fish from juveniles to adults with lower population densities than in the present study. In other researches, pH adjustments have been made, and nutrients have been added to supplement the lack provided by the fish wastewater, among the previously found investigations carried out by Wortman (2015), who worked with electrical conductivities and pH, obtaining a height of 76.4 cm in the treatment with the best conditions and with external nutrient supplements. In the case of the present study, unlike those previously mentioned, no pH adjustment was made, and no addition of nutrients was carried out, so it indicates that the density of the fish in their early stages of production provides the necessary nutrients for the production of tomato, obtaining results comparable with those carried out by other authors and with respect to the hydroponic culture used as a reference of a tomato crop under ideal conditions.

Tomato growth results are directly related to the amount of nitrogenous forms present in aquaculture water. Although at the beginning the fish density was higher in the adults, due to the size of the animals entered into the culture, the nitrogen excretion was at all times higher for fingerlings and juveniles, which caused greater assimilation of these nutrients by tomato crop. On the other hand, even though the hydroponic culture control had a significantly higher amount of nitrogenous elements in addition to the pH being controlled, the production was not significantly higher, indicating that nutrients in the water from fish, having gone through the metabolic process, were found in a more assimilable form by the plant. However, it is necessary to conduct a more detailed evaluation of the amount and form of these nitrogenous forms and their effect on each phenological stage of the tomato crop.

CONCLUSIONS

A comparison of three productive stages (fingerling, juvenile, and adult) of tilapia *O. niloticus* in an aquaponic system with tomato and a fertilized hydroponics system as control, was presented in this research. Based on the results and in comparison with control system, it might be concluded that wastewater from the fingerling and juvenile culture of tilapia in a hyper intensive system is the best option for tomato *S. lycopersicum* growth; on the other hand, residual water of adult of tilapia did not give good results in the growth of the vegetable culture. So, an aquaponic culture for the production of tomato with tilapia is not recommended with adult fishes. According to the data presented, the aquaculture system density did not affect the fish's survival in any productive stages and growth or health. In vegetable culture, significant differences were registered in comparison with hydroponic systems, which indicate a deficiency in the amount of available macro and micronutrients or some factor (such as pH) that could limit the nutrients' assimilation capacity available in the system. This research might improve the use of wastewater from aquaculture systems in integral systems, such as aquaponics, with greater use in fingerling and juvenile stages. Thus, developing a zero-discharge aquaponic system with high efficiency is essential for environmental and economic sustainability.

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