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Aquaponics using salinized water

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Resumo - A aquaponia aproveitando água salinizada

A aquaponia é uma técnica que integra a produção de peixes com o cultivo de plantas sem solo, utilizando efluentes da aquicultura para nutrir as hortaliças, promovendo um ciclo sustentável de nutrientes, contribuindo para a conservação dos recursos naturais, reduzindo a utilização de água, fertilizantes e pesticidas. A eficiência na utilização da água pode chegar a 90%, sendo uma alternativa orgânica, pois no semiárido brasileiro a escassez de água é um grande desafio. Assim, essa técnica apresenta-se como uma solução viável para a produção de alimentos, onde a utilização de poços artesianos salinos representa uma solução promissora frente às limitações hídricas locais. Logo, o objetivo deste estudo foi avaliar o desempenho da tilápia (*Oreochromis niloticus*) com a produção integrada de alface (*Lactuca sativa*), utilizando água salobra. A duração do experimento foi de 28 dias, em delineamento inteiramente casualizado, com um tratamento controle e um tratamento salobro 5‰, sendo três repetições de cada. A alface do tratamento controle apresentou maior crescimento em comprimento em relação à água salobra ($p < 0{,}05$), entretanto não houve diferença significativa no peso e no número de folhas entre os tratamentos, apesar da tendência de maior número de folhas no controle 29,11±1,78 ($p = 0{,}069$). Os peixes do tratamento controle apresentaram peso médio individual, ganho de peso e taxa de crescimento específico significativamente superiores em comparação ao tratamento com água salobra ($p < 0{,}05$). A biomassa final também foi maior no controle. Por outro lado, não houve diferença significativa no comprimento final, mortalidade, fator de condição e coeficiente de variação do peso entre os tratamentos. Conclui-se que a aquaponia com água salobra reduz o rendimento e crescimento de plantas e peixes, no entanto sob a perspectiva do aproveitamento de água percebe-se a viabilidade da aplicação de água salinizada na produção de alimento através da aquaponia.

Palavras-chave: Sustentabilidade; produção de alimento; tilápia; alface; semiárido.

Abstract - Aquaponics using salinized water

Aquaponics is a technique that integrates fish production with soilless plant cultivation, using aquaculture effluents to feed vegetables, promoting a sustainable nutrient cycle, contributing to the conservation of natural resources, and reducing the use of water, fertilizers, and pesticides. Water use efficiency can reach 90%, and is an organic alternative, since water scarcity is a major challenge in the Brazilian semiarid region. Thus, this technique presents itself as a viable solution for food production, where the high use of artesian saline wells represents a promising solution to local water limitations. Therefore, the objective of this study was to evaluate the performance of tilapia (*Oreochromis niloticus*) with integrated lettuce (*Lactuca sativa*) production using brackish water. The experiment lasted 28 days, in a completely random pattern, with a control treatment and a 5‰ brackish treatment, with three repetitions of each treatment. Lettuce in the control treatment showed greater growth in length compared to the brackish water treatment ($p < 0.05$); however, there was no significant difference in weight of leaves between treatments, despite the tendency for a slightly greater number of leaves in the control treatment (29.11 ± 1.78 ($p = 0.069$). Fish in the control treatment showed significantly higher individual average weight, weight gain, and specific growth rate compared to the brackish water treatment ($p < 0.05$). Final biomass was also higher in the control treatment. However, there was no significant difference in final length, mortality, condition factor, and coefficient of variation of weight between treatments. It is demonstrated that aquaponics with brackish water reduces the yield and growth of plants and fish; however, from the perspective of water use, the viability of applying salinized water in food production through aquaponics is acknowledged.

Keywords: Sustainability; food production; tilapia; lettuce; semiarid.

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Resumen - Acuaponía con agua salinizada

La acuaponía es una técnica que integra la producción de peces con el cultivo de plantas sin suelo, utilizando efluentes de acuicultura para alimentar vegetales, promoviendo un ciclo de nutrientes sostenible, contribuyendo a la conservación de los recursos naturales y reduciendo el uso de agua, fertilizantes y pesticidas. La eficiencia del uso del agua puede alcanzar el 90% y es una alternativa orgánica, ya que la escasez de agua es un desafío importante en la región semiárida brasileña. Por lo tanto, esta técnica se presenta como una solución viable para la producción de alimentos, donde el alto uso de pozos artesianos representa una solución prometedora a las limitaciones hídricas locales. Por lo tanto, el objetivo de este estudio fue evaluar el desempeño de la tilapia (*Oreochromis niloticus*) con la producción integrada de lechuga (*Lactuca sativa*) utilizando agua salobre. El experimento duró 28 días, en un diseño completamente aleatorizado, con un tratamiento de control y un tratamiento salobre al 5‰, con tres réplicas de cada uno. La lechuga en el tratamiento de control mostró un mayor crecimiento en longitud en comparación con el tratamiento de agua salobre ($p < 0,05$); Sin embargo, no hubo diferencia significativa en peso y número de hojas entre tratamientos, a pesar de la tendencia a un mayor número de hojas en el tratamiento control (29,11 ± 1,78 ($p = 0,069$). Los peces en el tratamiento control mostraron un peso promedio individual, ganancia de peso y tasa de crecimiento específico significativamente mayores en comparación con el tratamiento con agua salobre ($p < 0,05$). La biomasa final también fue mayor en el tratamiento control. Por otro lado, no hubo diferencia significativa en longitud final, mortalidad, factor de condición y coeficiente de variación de peso entre tratamientos. Se concluye que la acuaponía con agua salobre reduce el rendimiento y crecimiento de plantas y peces; sin embargo, desde la perspectiva del uso del agua, se percibe la viabilidad de aplicar agua salinizada en la producción de alimentos mediante acuaponía.

Palabras clave: Sostenibilidad; producción de alimentos; tilapia; lechuga; semiárido.

Introduction

Aquaponics is an innovative technique that combines aquaculture (fish farming) with hydroponics (soilless plant cultivation), using aquaculture effluent to nourish the plants. This sustainable approach offers a solution to several environmental and resource problems, such as water scarcity, environmental pollution, rising fertilizer costs, and the degradation of fertile soils (Goddek et al., 2019). Cultivation projects such as hydroponics and crop rotation promote environmental education and sustainable development, encouraging the reuse of waste and the participation of the school community (Ferreira, 2021). This integrated system, which combines fish farming with the cultivation of fruit and vegetable plants, promotes a sustainable nutrient cycle. This model also serves as a practical tool for teaching students the importance of sustainability, conservation of natural resources, and reduced environmental impact. Thus, a direct understanding of how aquaponics works helps develop environmental awareness of those who practice it, raising awareness of sustainable agricultural practices. Furthermore, aquaponics serves as a tool for the development of family farming, as aquaponic farming offers higher yield rates, faster growth, and lower water consumption compared to traditional farming methods while also eliminating soil-related disadvantages and requiring less water (Kulkarni et al., 2019).

The popularity of aquaponics has grown significantly, both in scientific and commercial applications. According to Goddek et al. (2019), decoupled aquaponic systems are becoming more common than coupled systems (based on feeding the system with known amounts/values of nutrient input), with deep-water culture components and media beds being considered ideal for commercial and research applications, respectively. Species such as tilapia (*Oreochromis niloticus*) and dark leafy vegetables have proven particularly successful in these systems. Aquaponics water use efficiency can reach 90%, eliminating the use of pesticides and reducing the need for fertilizers, making it a green and sustainable technology. However, large-scale implementation faces challenges, such as obtaining organic certification and legislative recognition, as well as cost and complexity barriers associated with the integration of intelligent systems and automation (Ibrahim; El-Sawah, 2022). For this technology to reach its full potential, further development of automated systems, supportive policies, and continued research into nutrient optimization and the role of plant growth-promoting microorganisms are necessary (Love et al., 2015). The economic viability of aquaponics is also a point of discussion. Research indicates that, although many practice aquaponics as a hobby or on a small scale, there is growing interest in its commercial application, especially in arid regions suffering from water shortage. Case studies in different countries show that aquaponics can be a viable solution for food production in urban areas and regions with limited resources (Love et al., 2015). Water is known to be a crucial factor in the Brazilian

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semiarid region, so efficient and correct management is another fundamental issue for food production and future development (Jeon et al., 2015).

Therefore, in the Brazilian semiarid region, water scarcity requires specific technologies for the use and conservation of water resources, with a focus on unconventional and low-cost technologies (Cirilo; Montenegro & Campos, 2016). Due to the scarcity of freshwater in certain locations, alternatives for food production are being developed to utilize available resources for some crops, even brackish waters. Therefore, using salinized waters, often not used for consumption, with the aim of producing animal and vegetable protein, through aquaponics, is a desirable alternative, but it needs to be tested. The objective of this work is to evaluate the zootechnical performance of tilapia with the integrated production of lettuce, using brackish water.

Material and Methods

The experiment was conducted at the Center for Fisheries and Aquaculture Studies (NEPA), part of the Fisheries Engineering Program, as part of the AquaEscola project: cultivating fish and vegetables in an integrated production system. Six aquaponic systems of equal volume were set up, three replicates with 5° salinized water (Ts_1, Ts_2, Ts_3) and the other three with 0° freshwater, defined as the control treatment (Tc_1, Tc_2, Tc_3). Each treatment consisted of a main PVC fish cultivation unit (tank) with a volume of 150 liters, using 50 useful liters, connected to a biological filtration unit with 30 liters of media. A 1,000 L/h circulation pump sent the water through vegetable cultivation channels, returning to the fish cultivation tank, at an approximate final flow rate of 700 L/h. The fish chosen was tilapia (*Oreochromis niloticus*), kept at a density of 10 kg/m³, with an average initial weight of 44 ± 2.54 g and an average length of 13.47 ± 0.31 cm. Each experimental unit began with 10 fish (average biomass of 440 g) and 10 units of vegetables. The vegetable chosen was lettuce (*Lactuca sativa*), which was stocked starting at a feeding rate of 50 g/m² of leafy vegetables.

The fish were sourced from LABAQUA, part of the Center for Fisheries and Aquaculture Studies, as fingerlings (fish weighing over 30 g), where they had already acclimated. One subset (50 fish) remained in freshwater, and another (50 fish) was acclimated to a salinity of 5‰, with a daily increment of 1‰, for five days. Immediately afterward, both subsets were randomly transferred to their respective treatments. The fish were fed 5% of their body weight per day, with 46.3 g/day of commercial feed (2 mm, 33% CP) administered twice daily, morning and afternoon. This feed supply provided the necessary nutrients for 1.5 m^2 of vegetable crop, supporting up to 30 units.

The experiment was conducted for 28 days using lettuce (*Lactuca sativa*), a curly variety recommended for hydroponic production, during which time it reached harvest time. The seedlings were produced in the greenhouses of the Water and Soil Engineering Center Laboratory (UFRB), in a plastic tray with cells filled with inert substrate at a density of one seed per cell, and kept in a protected environment. Irrigation occurred twice daily with a plastic watering can for 14 days. After this period, the seedlings were transferred to aquaponic profiles, and the test plot was acclimated to brackish water.

The experiment used an NFT (Nutrient Film Technique) hydroponic system made of 75 mm PVC pipes with 10 openings, each with a 50 mm diameter opening and a 5% slope for the flow of water from the filtration system (Figure 1). A 15 cm spacing between plants and the same distance between profiles were maintained. The residual ammonia degraded by biological filtration was the aquaponic nutrient solution, presenting a continuous flow, being pumped to the aquaponic system, circulating water 24 hours a day, at a flow rate of 800 L/h (there is a loss of pump pressure), returning to the fish tank by gravity.

Three replicates of the vegetable were used, with 10 lettuce plants, as well as 10 fish. Water quality parameters were analyzed, with ammonia, pH, and nitrite measured biweekly, and salinity, conductivity, TDS, O_2, and temperature measured weekly. In the Ts, salinity was monitored using a multiparameter probe, corrected, if necessary, by adding filtered water, as only water evaporates, concentrating the salts.

After the experimental period (28 days after planting), the vegetables were harvested, and phytotechnical parameters were evaluated, such as counting the number of leaves per plant; the length of each leaf; root length (from the stem insertion point to the root tip) using a graduated ruler; and plant weight. Fish performance was also assessed at the end of the experiment, measuring average total length and average total weight, and calculating specific growth rate, weight gain, and feed conversion. The results were subjected to Student's t-test to compare the means of two groups of data (α=0.05).

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Figure 1. Overview of the aquaponic experiment

Results and discussion

Before the experiment began, four samples were collected for destructive analysis of the plants (*Lactuca sativa*) after 14 days of nursery growth to obtain baseline data. The plants had an average length of 16.80 ± 0.78 cm and an average weight of 14.67 ± 2.73 g. Stem length was 1.17 ± 0.12 cm, while the average number of leaves per plant was 8.33 ± 0.88 g. Furthermore, the average root length was 12.18 ± 0.85 cm. These values represent the baseline conditions of the lettuce plants prior to the application of the experimental treatments and serve as a reference for subsequent analyses.

The values of the phytotechnical parameters of the crisp lettuce over the 28 days are presented in Table 1, which allows us to observe the performance of the plants present throughout the experiment. The main results highlight significant differences in leaves length and root height of the plant.

Table 1. Average performance of lettuce (*Lactuca sativa*) in different treatments in integrated cultivation with tilapia.

Plant parameters	Tc	Ts
Length (cm)	24,55 ± 0,76 *	16,81 ± 0,59
Weight (g)	76,53 ± 3,05	83,08 ± 1,38
Stem (cm)	1,03 ± 0,05	0,94 ± 0,02
Leaves	29,11 ± 1,78	24,21 ± 0,87
Root (cm)	12,18 ± 0,85 *	14,25 ± 1,77

* Indicates a significant difference between treatments ($p<0.05$) by Student's t-test.

Lettuce grown in the control treatment showed significantly greater growth than in brackish water ($p < 0.05$), suggesting that salinity may have negatively influenced plant development. According to Poss et al. (1999), lettuce is considered a salinity-sensitive crop, and high levels can cause reduced growth due to osmotic stress, which hinders the absorption of water and essential nutrients. We observed a reduction in plant length in the brackish treatment, where according to Chourasia et al. (2022), saline stress affects plant height, leaf area, and biomass yields, as osmotic adjustments divert resources from vegetative growth to osmotic adjustments. Despite the difference in length, lettuce weight did not differ significantly between treatments. This indicates that, according to Shannon and Grieve (1998), although the plant grew less in height in brackish water, it may have developed other adaptation mechanisms, such as greater accumulation of biomass in underground structures or greater water retention in the leaves.

Research, such as that by Munns and Tester (2008), indicates that some plants may experience reduced growth but maintain similar weight due to physiological changes, such as increased leaf thickness and accumulation of osmoprotective compounds. Leaf number, an essential element from a commercial perspective, was higher in the control treatment (29.11 ± 1.78) than in brackish water (24.21 ± 0.87), but this difference was not statistically significant ($p = 0.069$), so we cannot infer that the presence of salt in the cultivation water has a negative impact. Similarly, stem length did not show a significant difference ($p = 0.136$) between treatments, indicating that salinity did not directly influence this variable. Leaf number and stem growth are affected by water and nutrient availability (Yang and Kim, 2020).

Among the results without statistical significance, we note that root length was greater in brackish water, suggesting, based on Flowers and Colmer (2015), that the plant may have adapted its root system to improve water and nutrient absorption in an environment with higher salt concentrations. Under saline stress conditions, some plants may develop a deeper root system to seek water in less saline layers of the soil or nutrient solution (Taiz et al., 2017).

Regarding fish, this study evaluated the zootechnical performance of Nile tilapia (*Oreochromis niloticus*) grown in an aquaponic system integrated with lettuce (*Lactuca sativa*), comparing the effects of a control treatment with freshwater and a treatment with brackish water. The results regarding specific growth rate and weight gain of the fish are presented in Table 2. The monitored water quality parameters were largely within the limits indicated by Somerville et al. (2014).

Table 2. Average zootechnical performance of Nile tilapia (*Oreochromis niloticus*) in different treatments in integrated cultivation with lettuce.

Growth parameters	Tc	Ts
Initial Weight (g)	46,30 ± 0,40	45,23 ± 0,67
Final Weight (g)	57,37 ± 0,79 *	52,47 ± 0,38
Initial Length (cm)	13,70 ± 0,06	13,23 ± 0,20
Final Length (cm)	14,77 ± 0,12	14,40 ± 0,12
Weight Gain (g)	11,07 ± 1,18 *	7,23 ± 0,28
Specific Growth Rate	8,54 ± 0,41 *	7,06 ± 0,14
Coefficient of Variation	19,89 ± 0,11	22,05 ± 2,59
Condition Factor	1,79 ± 0,05	1,75 ± 0,02

* Indicates a significant difference between treatments ($p<0.05$) by Student's t-test.

At the end of the experimental period (28 days), it was observed that fish in the control treatment reached a significantly higher average individual weight (57.37 ± 0.79 g) compared to the brackish water treatment (52.47 ± 0.38 g; $p = 0.005$), resulting in a total biomass per tank of 573.7 g and 524.7 g, respectively. This statistically significant difference suggests that brackish water salinity had a negative impact on tilapia weight growth, which is in line with the literature (El-Sayed, 2019; Suresh and Lin, 1992), which indicates a better performance of the species under low salinity conditions. Similarly, weight gain was significantly higher ($p = 0.035$) in the control treatment (11.07 g) compared to the brackish water treatment (7.23 g). The specific growth rate (SGR) also followed this trend, being significantly higher ($p = 0.026$) in the control (8.54% day^{-1}) than in brackish water (7.06% day^{-1}). These results reinforce the hypothesis that salinity affects tilapia metabolism, possibly demanding greater energy expenditure for osmoregulation processes, as suggested by Wu et al. (2008), which consequently reduces its growth rate.

Despite a trend toward greater final length in the control group (14.77 cm) compared to the brackish water group (14.40 cm), this difference was not statistically significant ($p = 0.093$). This indicates that salinity may have affected mass accumulation more than linear growth of the fish during the evaluated period. The lack of significance in length can, in part, be explained by compensatory growth mechanisms in response to environmental conditions, as mentioned by Lima et al. (2018). During the experiment, total mortality was five animals, with no statistical difference between treatments ($p>0.05$). Additionally, the condition factor ($p = 0.545$) and the coefficient of variation of final weight ($p = 0.451$) did not show significant differences between groups, suggesting that both treatments maintained a similar general nutritional status and uniformity in fish growth within each group, despite the impact of salinity on overall performance.

The results of this study demonstrate that the use of brackish water, under the conditions tested, negatively impacted the zootechnical performance of Nile tilapia in terms of final weight and specific growth rate. Although final length and condition and variation parameters were not significantly affected, the observed tendency corroborates the evidence presented by Spradlin and Saha (2022), who highlight the strategic potential of using brackish or saline water in aquaculture systems—particularly in arid or coastal regions—as an alternative to reducing the demand for freshwater resources. These findings reinforce the need to incorporate salinity as a critical variable in tilapia aquaponics farming, especially when using alternative water sources, aiming at system sustainability.

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Conclusion

It is demonstrated that aquaponics with brackish water, at a level of 5‰, reduces the yield and growth of lettuce (*Lactuca sativa*) and tilapia (*Oreochromis niloticus*). However, from the perspective of water use in regions with freshwater scarcity, the viability of applying salinized water in food production through aquaponics is acknowledged, as this water is abundant in several regions of the Brazilian semiarid region through wells.

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