UFSM

CIÊNCIA e NATURA

ISSN 2179-460X
OPEN ACCESS

Ci. e Nat., Santa Maria, e74160, v. 47, 2025 • https://doi.org/10.5902/2179460X74160
Submitted: 13/02/2023 • Approved: 10/01/2025 • Published: 01/04/2025

Environment

Tropical aquaponic production of lemon balm, *Melissa officinalis*, using different *Astyanax bimaculatus* fingerling stocking densities

Produção aquapônica tropical de erva cidreira, *Melissa officinalis*, utilizando diferentes densidades de estocagem de *Astyanax bimaculatus*

Bernardo Ramos Simões Corrêa[I], **Rodrigo Diana Navarro**[I]

[I] Universidade de Brasília, Brasília, DF, Brasil

ABSTRACT

The relationship between the constituent organisms of aquaponics - fish, plants, and microorganisms - needs to be in biological harmony to favor the maximum performance of the species. Lemon balm (*Melissa officinalis*), a food and medicinal plant, as well as *Astyanax bimaculatus*, are species that can add value to the final products of aquaponics. The present experiment tested five treatments with different stocking densities of *A. bimaculatus* fingerlings (0.0, 0.1, 0.2, 0.3, and 0.4 fish L-1; T1, T2, T3, T4, and T5, respectively) in association with lemon balm at a density of 24 plants m-2 in media bed aquaponic systems installed in a greenhouse. The experimental design was completely randomized with three replications for each treatment, totaling 15 aquaponic systems analyzed. The results showed that for fish growth, T2 presented the best performance results, followed by T3 and T4, and finally T5; while for plants it was T3, followed by T4 and T5 which did not show differences between them, followed by T2, and finally T1. In all treatments, animal and plant growth were observed. The studied aquaponic systems demonstrated their viability for the production of the species, presenting satisfactory results, which can be interesting for further studies and producers.

Keywords: Water recirculation; Nutrient recycling; Medicinal plants

RESUMO

A relação entre organismos constituintes da aquaponia, peixes, plantas e microrganismos precisam estar em harmonia biológica para favorecer o máximo desempenho das espécies. A erva-cidreira *(Melissa officinalis*), planta alimentícia e medicinal, e *Astyanax bimaculatus* são espécies que podem agregar valor aos produtos finais aquapônicos. O presente experimento testou cinco tratamentos diferindo por densidades de estocagem de alevinos de *A. bimaculatus* (0,0, 0,1, 0,2, 0,3 e 0,4 peixe L-1;

T1, T2, T3, T4 e T5, respectivamente) em associação com erva-cidreira, na densidade de 24 plantas m-2, em sistemas aquapônicos de substrato instalados em casa de vegetação. O delineamento experimental foi inteiramente casualizado com três repetições para cada tratamento, totalizando 15 sistemas aquapônicos analisados. Os resultados demonstraram que, para o crescimento dos peixes, o T2 foi o que apresentou os melhores resultados de desempenho, seguido do T3 e T4, e por último o T5, enquanto para as plantas foi o T3, seguido do T4 e T5, que não apresentaram diferenças entre si, seguido por T2 e T1, por último. Em todos os tratamentos, observou-se crescimento animal e vegetal. Os sistemas aquapônicos estudados demonstraram sua viabilidade para a produção da espécie apresentando resultados satisfatórios, o que pode ser interessante para futuros estudos e produtores.

Palavras-chave: Recirculação de água; Reciclagem de nutrients; Plantas medicinais

1 INTRODUCTION

One of the main water-related challenges that needs to be addressed is the production of more food while using less water. As agriculture faces complex challenges to satisfy an estimated population of nine billion by 2050, the Food and Agriculture Organization (FAO) estimates that global food production must increase by 70% to meet this demand (FAO 2017). Therefore, studies focusing on more efficient, equitable, and ecological use of water in agriculture are necessary, and this escalating requirement poses significant challenges to conventional agricultural practices, particularly regarding water scarcity and sustainable resource management (FAO 2020). Agriculture currently accounts for approximately 70% of global freshwater use, a figure that is unsustainable in many regions facing severe water shortages, and with nearly 2 billion people already living in areas of high water stress, the need for innovative, sustainable solutions to food production has never been more urgent (UNESCO 2021).

In this context, aquaponics has emerged as a promising solution that integrates aquaculture and hydroponics into a single, sustainable food production system. Aquaponics systems utilize the symbiotic relationships between fish and plants, where the waste produced by fish provides essential nutrients for plant growth, while plants help filter and purify the water for the fish (Rakocy et al. 2006). This closed-loop system significantly reduces water consumption—estimates suggest it can achieve remarkable water use efficiency, up to 90% (Ibrahim et al. 2023). The technology thus addresses two critical challenges: the need for increased food production and the sustainable management of freshwater resources.

Aquaponic systems are a branch of recirculating aquaculture technology in which plant crops are included either to diversify the production of a business, provide extra water filtration capacity, or a combination of the two (Espinal & Matulié, 2019). In aquaponic systems, nutrient uptake should be maximized for healthy plant biomass production without neglecting the best welfare conditions for fish in terms of water quality (Yildiz et al. 2017).

Moreover, aquaponics has the potential to contribute to food security in urban areas, where land availability is limited, and transportation costs can exacerbate food prices. Also, food can be grown indoors in a fully controlled environment, making it more resilient to climate change (Channa et al. 2024). However, despite its potential, aquaponics is not without challenges. High initial setup costs and the need for technical expertise can deter widespread adoption, particularly in developing countries. Additionally, aquaponics is a complex ecosystem with many critical parameters that must be closely monitored and maintained, such as dissolved oxygen (DO), ammonia, pH, temperature, and exposure to sunlight (Channa et al. 2024).

Understanding the cost-effectiveness of aquaponic systems compared to traditional agricultural practices is vital for promoting wider adoption. Studies have shown that despite aquaponics systems generally having higher start-up costs currently, its potential to be economically viable when undertaken with local materials is very high (Obirikorang et al. 2021). With aquaponics primary selling point of being a sustainable system, developing commercial systems which are truly sustainable is of utmost value (Yep & Zheng 2019).

Over the past decades, research in ornamental species has indicated exponential growth, especially within the aquaculture industry, and it is expected that the value of ornamental trade will increase significantly in the next few years (Peh & Azra 2025). Similarly, nowadays, roughly 80% of the world's population gets their healthcare mostly from plants and plant extracts, and according to a World Health Organization (WHO) forecast, the worldwide herbal industry would reach $5 trillion by the year 2050 (Parvin et al. 2023). Incorporating medicinal plants such as basil, mint, and echinacea into aquaponic systems allows producers to tap into this lucrative market while promoting biodiversity and ecological sustainability.

The production of ornamental and food fish has become an important avenue for income Generation in rural areas. According to the Brazilian Institute of Geography and Statistics (IBGE), the aquaculture sector in Brazil has experienced robust growth, with ornamental fish sales contributing substantially to this trend (IBGE 2021). Among various species, the lambari (*Astyanax* sp.) has gained popularity due to its low production costs and adaptability to diverse aquaculture systems. Fish from the genus *Astyanax* can be raised by small rural or urban producers in family production systems (Lopes et al. 2013) and can be used as snacks for human consumption or as forage fish in aquarium stores and public aquariums for environmental enrichment and to feed larger carnivorous species (Silva et al. 2011). Other advantages of *Astyanax* sp. production include standardization of size, greater traceability, and regularity in supply (Gonçalves et al. 2017).

Lemon balm (*Melissa officinalis* L.) is one of the medicinal and aromatic plants most important and with potential in the market, and the species is part of the species list medicinal products regulated by the National Health Surveillance Agency of Brazil, and its oil essential has proven pharmacological properties in several countries. The high market value of the herb provides small-scale farmers with the potential for significant profit margins, especially when leveraging organic and sustainable production methods (Alves 2017).

Lemon balm is a perennial aromatic herb that has a lemon-like aroma and belongs to the Laminaceae family (Khalid et al. 2008), been one of the most valuable medicinal plants in herbal medicine (Sabry et al. 2023). This herb is traditionally used as medicine for relieving neurogenic disorders, insomnia, and stress due to its spasmolytic and sedative properties (Kennedy et al. 2002). In addition, the antibacterial and antioxidative effects of its essential oil are well documented (de Assis et al. 2020; Patora & Klimek 2002; Venskutonis et al. 2005). Lemon balm is widely used as a resource for fragrances, phytomedicine, and teas (Carnat et al. 1998) and therefore attracts continued interest for its mass production (Son et al. 2021).

It grows well in full sun, but it also grows in partial shade (Sorensen 2000). When the plants grow in semi-shade, they produced larger leaves and habitat than those grown in sunny condition. Lemon balm can rapidly grow at temperature range 15 to 35°C and requires 500 to 600 mm precipitation well distributed throughout the growing season, otherwise it should be irrigated (Moradkhani et al. 2010). Vegetative propagation is one of the most used ways to produce seedlings and can be carried out using different techniques, including cuttings, grafting and layering (Hartmann et al. 2018). Smallholders can benefit from low-cost propagation methods and this method helps to maintain the quality of the plant, as it has the advantage of preserving the characteristics of the mother plant and, as it is a relatively simple technique, it is the most economically viable, as, from a mother plant, one can obtain a significant amount of seedlings (Masiero et al. 2021).

Since there is a range of plant species that can be cultivated in aquaponics, the choice of species that adds final value to the aquaponic product must be highlighted. Considering that leafy plants, such as some aromatic herbs, are less demanding in nutrients and stand out in aquaponic systems, the present study was conducted to assess the growth performance and optimize the stocking density of *Astyanax bimaculatus* (Linnaeus, 1758) fingerlings in lemon balm (*Melissa officinalis*) media bed tropical aquaponic systems production.

2 MATERIAL AND METHODS

The experiment was carried out between August 24th and October 14th, 2020, totaling 51 days of cultivation, in 15 identical aquaponic systems installed in a greenhouse at the Sustainable Aquaculture Center at Água Limpa Farm (FAL), from the University of Brasília - UnB, Brazil. The study was approved by the institutional ethics committee of the University of Brasília (CEUA/UnB protocol code 115/2019 of August 20th, 2020) for studies involving animals. The aquaponic systems rely on an ebb-and-flow water pattern with one loop. The experimental design, completely randomized, consisted of five treatments (one of them being the control) with three repetitions, differentiated by fish stocking densities, totaling fifteen aquaponic units.

The aquaponic units are made up of 310L volume polypropylene water tanks for fish production, filled to 300L, and 0.25 m^2 polypropylene planters filled with expanded clay, in addition to a water pump (Grupo Sario®, Sariobetter SB1000C, Brazil) that transports water from the fish pond to the vegetable crop. Aeration was constant by an air compressor (Group Boyu®, ACQ-003, Guangdong, China). The climate in the region is tropical with a dry season, type Aw in the Köppen-Geiger climate classification, with monthly average temperatures always above 18º C and annual rainfall around 1,540 millimeters, concentrated between October and April.

2.1 Fish Treatments

Astyanax bimaculatus fingerlings were stocked at five different densities: 0.0 fish L-1 (T1-Control), 0.1 fish L-1 (T2); 0.2 fish L-1 (T3); 0.3 fish L-1 (T4); and 0.4 fish L-1 (000, 100, 200, 300 and 400 fish m-3, respectively). The fingerlings were acquired from a reputable supplier. For animal growth analysis, initial and final biometrics were performed considering parameters of weight (g) and total length (cm) using a precision electronic digital scale (SF-400, manufactured in China) and pachymeter. Biweekly biometrics were performed to determine the mean fish weight for each treatment in order to correct the feed offer fixed at 4% of gross biomass weight. Growth indexes were also calculated to observe animal performance including specific growth rate (% d-1), protein efficiency ratio (PER), and feed conversion ratio (FCR). Fish were anesthetized with eugenol solution and euthanized according to recommended techniques (Fernandes et al. 2017; Viegas et al. 2020).

2.2 Plant analysis

The chosen plant species for the experiment was lemon balm, *Melissa officinalis*, which is widely known for its medicinal and food uses. The seedlings were acquired by planting the species in soil and pricking them for installation in planters in the aquaponic system. For plant growth, the parameters of weight (g), height (cm), and number of leaves (nos. plant-^{1}) were evaluated using a precision electronic digital scale (B-max® - SF-400, China), pachymeter, and manual counting, respectively. Plants were installed at a density of 24 plants m-^{2} and, as we used planters of 0.25 m^{2}, there were 6 plants for each aquaponic unit. At the end of the experiment, lemon balm plants and fish were dried at 60 ºC for 3 days in a drying oven and analyses of total nitrogen of plant parts and fish were performed using the Kjeldahl (1883) method with adaptations (Galvani & Gaertner, 2006).

2.3 Water analysis

In terms of water quality, the parameters of temperature (°C), pH, and dissolved oxygen concentration (mg/L) were measured weekly using specific probes for this purpose (Hanna® - HI 9813-6, Italy; Alfakit® - AT – 160, Brazil, respectively). At the end of the experiment, ion analyses were performed to determine the cations sodium - Na+ (mg/L-^{1}), potassium - K+ (mg/L-^{1}), ammonium - NH4+ (mg/L-^{1}), calcium - Ca2+ (mg/L-^{1}), and magnesium - Mg2+ (mg/L-^{1}), as well as the anions fluoride - F- (mg/L-^{1}), chloride - Cl- (mg/L-^{1}), nitrite - NO2- (mg/L-^{1}), nitrate - NO3- (mg/L-^{1}), phosphate -

PO43- (mg/L-¹), and sulfate - SO42- (mg/L-¹) in treatment water samples using an Ion Chromatograph, model 761 Compact IC, Methrohm (Herissau, Switzerland). For cation analyses, a Metrosep C2 ion exchange solution was used with a buffer solution of 4.0 mM Tartaric Acid and 0.75 mM Dipicolinic Acid (2.6-pyridinedicarboxylic acid) as eluent. For anion analyses, Metrosep Asup5 was used with a buffer solution of 3.2 mM sodium carbonate and 1.0 mM sodium hydrogen carbonate and a suppressor solution of 100 mM sulfuric acid was used in the ion suppression branch parallel to ultrapure water with a pre-set gradient of 50% (water/acid).

Comparative statistical analyses of biometric performances of animals and plants and water quality between treatments were performed using MaxStat® Lite version 3.60 and Statistica version 10 (Statsoft®). Analyses were carried out by one-way ANOVA test, Tukey test, and Dunn's test with significance fixed at 5%. Graphs were created by factorial ANOVA analyses.

3 RESULTS

3.1 Fish

The effect of different fish densities on fish growth (length and weight) was observed. Fish growth in terms of body weight (g), length (cm), weight gain (%), and length gain (%) of *A. bimaculatus* varied significantly ($p<0.05$) between treatments (Table 1).

Table 1 – Growth parameters of *Astyanax bimaculatus* fingerlings reared in media bed aquaponic system after a period of 51 days (Mean±SD)

(To be continued)

Parameters	T2	T3	T4	T5
Initial weight (g)	1.60 ± 0.06^{a}	1.67 ± 0.06^{a}	1.55 ± 0.15^{a}	1.73 ± 0.09^{a}
Final weight (g)	5.86 ± 1.48^{a}	4.62 ± 0.30^{ab}	3.82 ± 0.17^{ab}	2.80 ± 0.36^{b}

Table 1 – Growth parameters of *Astyanax bimaculatus* fingerlings reared in media bed aquaponic system after a period of 51 days (Mean±SD)

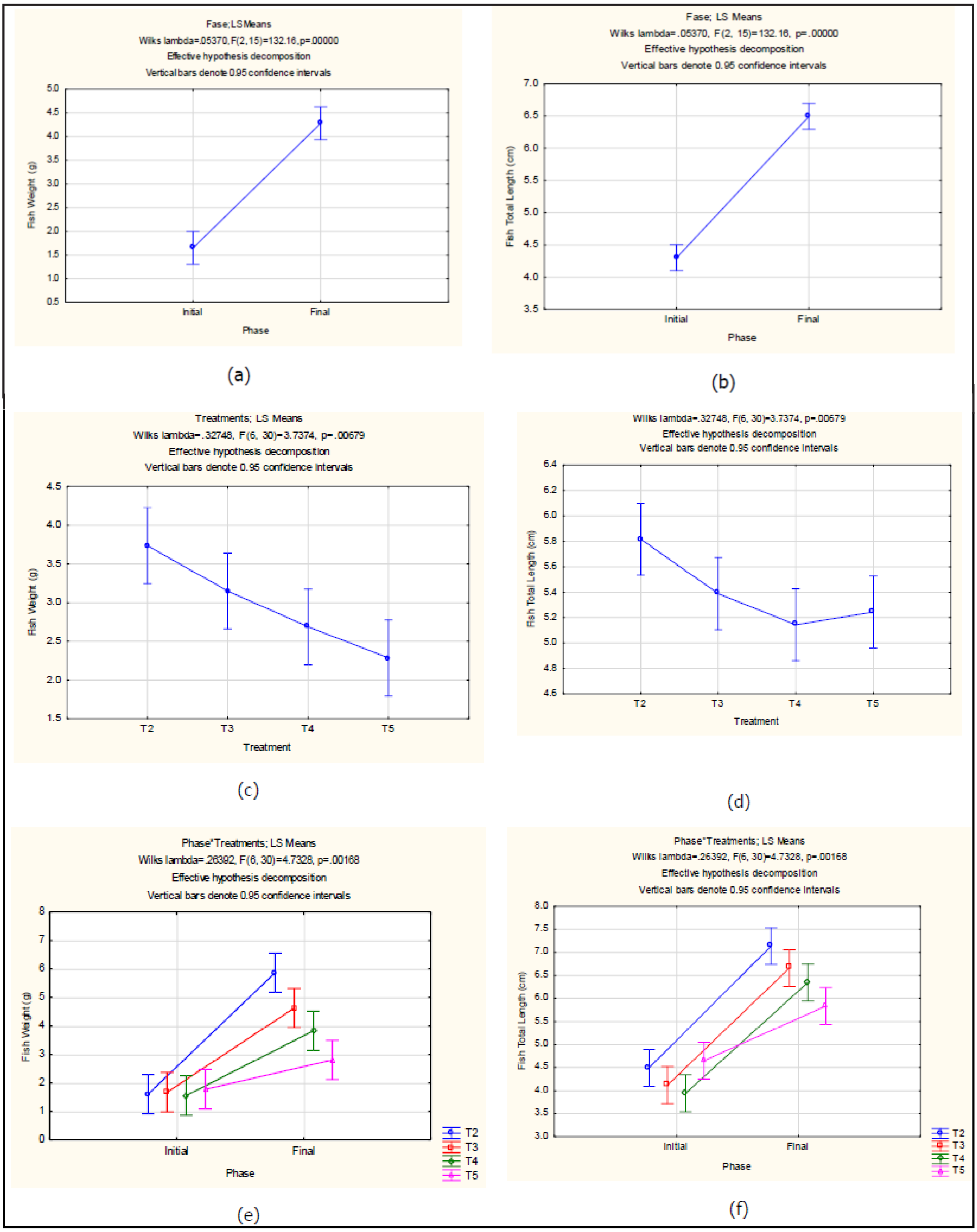
(Conclusion)

Parameters	T2	T3	T4	T5
Weight gain (%)	266.25	176.64	146.45	61.84
Initial length (cm)	4.49 ± 0.29^{a}	4.11 ± 0.16^{a}	3.94 ± 0.07^{a}	4.65 ± 0.68^{a}
Final length (cm)	7.13 ± 0.45^{a}	6.66 ± 0.11^{ab}	6.34 ± 0.14^{ab}	5.83 ± 0.15bc
Length gain (%)	58.79	62.04	60.91	25.37
Specific growth rate ($\%d^{-1}$) (SGR)	7.89 ± 2.82^{a}	5.46 ± 0.66^{ab}	4.19 ± 0.49^{ab}	1.89 ± 0.60^{b}
Protein efficiency ratio (PER)	1.90 ± 0.75^{a}	1.27 ± 0.19^{ab}	1.06 ± 0.08^{ab}	0.49 ± 0.15^{b}

*Values bearing same superscripts do not differ significantly (p>0.05) Source: Authorship (2023)

There were no initial differences in weight and length between treatments. For final weight and final length, T2 showed better results and, despite being similar to T3 and T4, was different from T5. For all fish performance parameters evaluated, T5 presented the lowest values and, even though fish growth was observed, this treatment seems to compromise animal welfare, making it desirable to use lower fish stocking densities (Fig 1). There was no mortality during the experiment.

Figure 1 – Graphs of fish performances during the experiment: (a) fish weight means for initial and final phase; (b) fish length means for initial and final; (c) fish weight means for each treatment considering the initial and final measures; (d) fish length means for each treatment considering the initial and final measures; (e) fish weight means for initial and final phase for treatment; (f) fish length means for initial and final phase



Source: Authors (2023)

3.2 Plants

Lemon balm growth in terms of mean weight (g), weight gain (%), mean length (cm), length gain (%) and mean leaves yield (nos. plant-¹) and leaves gain (%) showed differences between treatments (Table 2).

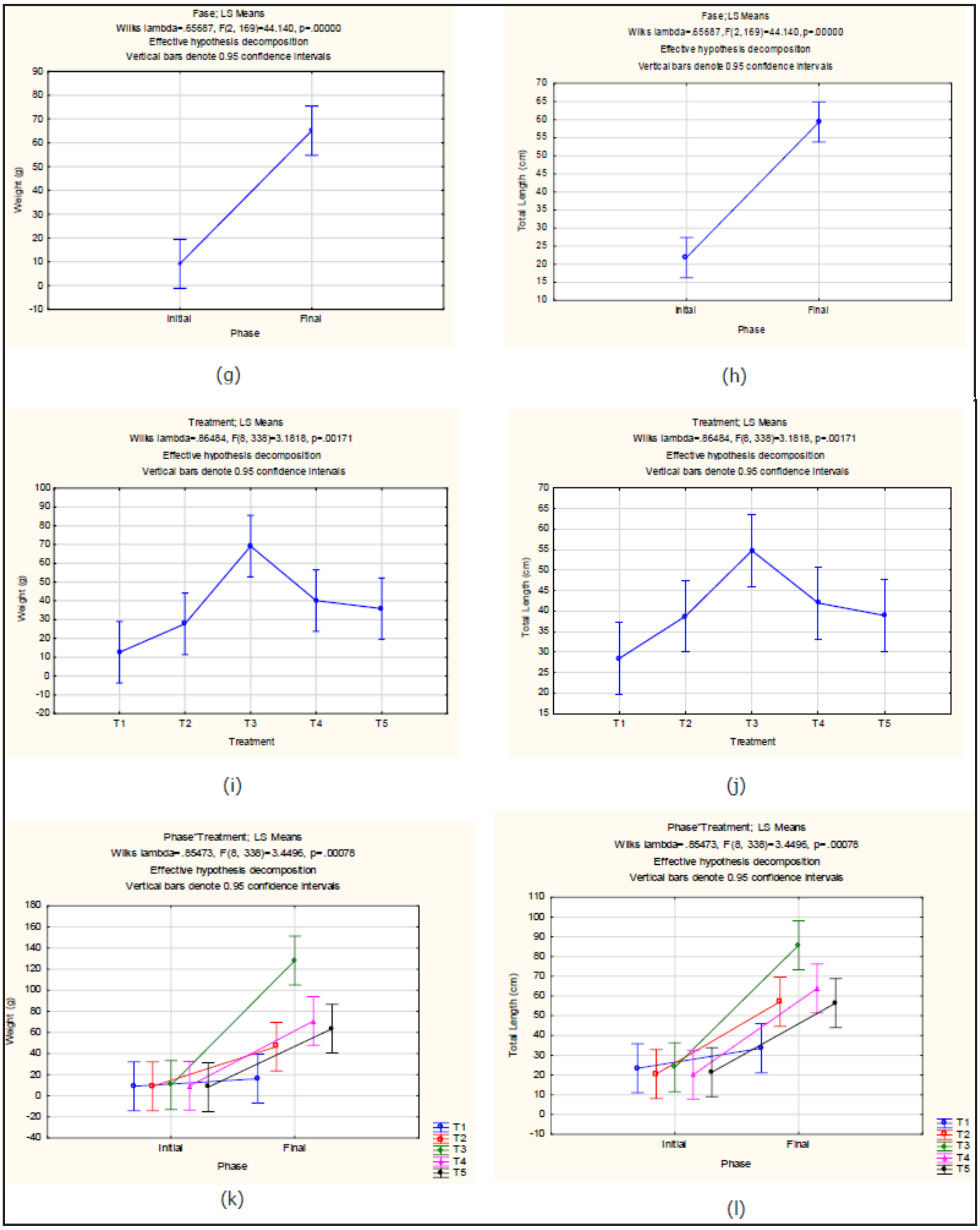
Table 2 – Growth parameters of lemon balm plants reared in media bed aquaponic system after a period of 51 days (Mean±SD)

	Treatments				
Parameters	**T1**	**T2**	**T3**	**T4**	**T5**
Initial weight (g/plant-¹)	9.04 ± 2.81^{a}	9.01 ± 4.98^{a}	10.17 ± 5.56^{a}	9.48 ± 5.73^{a}	8.17 ± 4.95^{a}
Final weight (g/plant-¹)	17.21 ± 10.42^{ab}	46.57 ± 43.65^{ab}	128.12 ± 116.20^{c}	75.01 ± 61.70^{abc}	63.62 ± 71.67^{abc}
Weight gain (%)	90.37	416.87	1,159.78	691.24	678.7
Initial length (cm)	23.36 ± 8.64^{a}	20.43 ± 7.82^{a}	23.85 ± 11.43^{a}	20.15 ± 10.12^{a}	21.40 ± 9.43^{a}
Final length (cm)	34.02 ± 13.56^{a}	53.67 ± 29.35^{ab}	70.87 ± 37.49^{b}	57.29 ± 25.19^{ab}	55.04 ± 32.23^{ab}
Length gain (%)	45.63	162.7	197.14	184.31	157.19
Initial leaves (n. plant-¹)	34.55 ± 13.24^{a}	24.5 ± 10.01^{a}	29.00 ± 18.70^{a}	31.66 ± 15.38^{a}	27.44 ± 13.23^{a}
Final leaves (n. plant-¹)	26.41 ± 16.09^{a}	114.72 ± 91.37^{ab}	261.05 ± 254.50^{b}	180.29 ± 181.59^{ab}	177.00 ± 205.68^{ab}
Leaves gain (%)	-23.56	368.24	800.17	469.45	545.04

*Values bearing same superscripts do not differ significantly (p>0.05) Source: Authors (2023)

For all treatments nourished by fish effluent, the percentage of gains in the number of leaves was above 300%, with the best treatment, T3, being 800%. It should be noted that leaves are the main product of lemon balm production, being used for the manufacture of pharmaceuticals or for use in cooking. Also, the weight and length values of lemon balm plants in all treatments showed growth between the initial and final phases, with the highest values at T3 (Fig 2). Despite the control treatment, T1, which has no fish, showing gains in weight and height, the plants of this treatment demonstrated that they were not under good nutrition conditions, with yellow-colored leaves and negative leaf gain (%), losing leaves at the end of the experiment.

Figure 2 – Graphs of plant performances during the experiment: (g) plant weight means for initial and final phase; (h) plant length means for initial and final phase; (i) plant weight means for each treatment considering the initial and final measures; (j) plant length means for each treatment considering the initial and final measures; (k) plant weight means for initial and final phase for treatment; (l) plant length means for initial andfinal phase for treatment



Source: Authors (2023)

3.3 Water

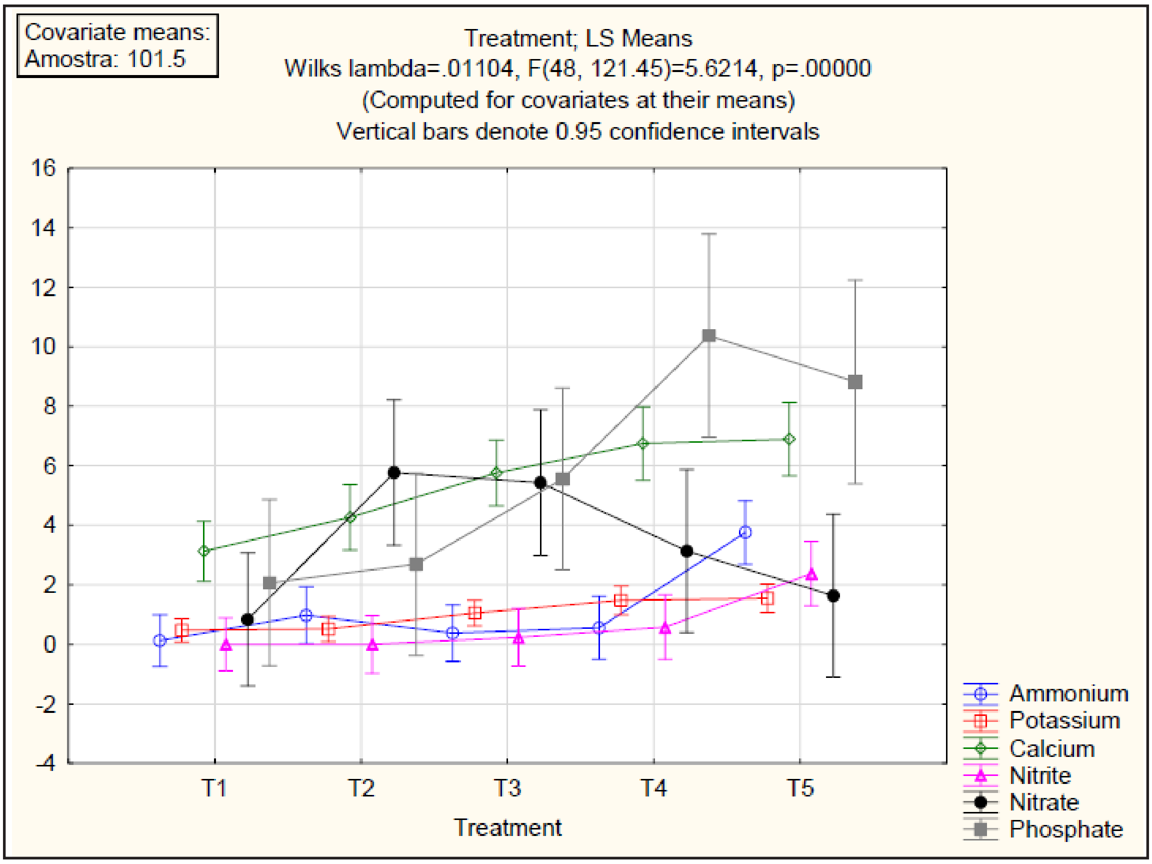
In the present study, the mean variation in average values of water temperature (ºC), pH, dissolved oxygen (mg/L-¹), sodium (mg/L-¹), ammonium (mg/L-¹), potassium (mg/L-¹), calcium (mg/L-¹), magnesium (mg/L-¹), fluoride (mg/L-¹), chloride (mg/L-¹), nitrite (mg/L-¹), nitrate (mg/L-¹), phosphate (mg/L-¹), and sulfate (mg/L-¹) were observed during the experimental period, as shown in Table 3 and Figure 3.

Table 3 – Water quality parameters recorded during the experiment (Mean±SD)

Parameters	**Treatments**				
	T1	**T2**	**T3**	**T4**	**T5**
Temperature (ºC)	24.56 ± 2.67^{a}	24.78 ± 2.61^{a}	24.84 ± 2.63^{a}	24.20 ± 2.51^{a}	24.21 ± 2.53^{a}
pH	6.1 ± 0.39^{a}	5.95 ± 0.45^{ab}	6.06 ± 0.46^{a}	5.79 ± 0.33^{b}	5.92 ± 0.33^{ab}
DO (mg/L-¹)	10.73 ± 3.47^{a}	9.91 ± 3.06^{a}	10.10 ± 2.91^{a}	9.65 ± 2.87^{a}	9.91 ± 3.04^{a}
Sodium (mg/L-¹)	5.47 ± 3.88^{a}	25.11 ± 47.92^{a}	40.16 ± 64.18^{a}	111.64 ± 199.74^{a}	54.76 ± 87.18^{a}
Ammonium (mg/L-¹)	0.12 ± 0.14^{a}	0.97 ± 0.74^{bc}	0.37 ± 0.31^{ab}	0.55 ± 0.42^{abc}	3.76 ± 3.51^{c}
Potassium (mg/L-¹)	0.47 ± 0.50^{a}	0.51 ± 0.35^{ab}	1.04 ± 0.37^{bc}	1.47 ± 0.61^{bc}	1.55 ± 1.27^{c}
Calcium (mg/L-¹)	3.13 ± 1.54^{a}	4.27 ± 1.58^{ab}	5.76 ± 1.52^{b}	6.74 ± 1.71^{b}	6.89 ± 2.24^{b}
Magnesium (mg/L-¹)	0.25 ± 0.20^{a}	0.27 ± 0.13^{ab}	0.45 ± 0.14^{b}	0.62 ± 0.24^{b}	0.64 ± 0.36^{b}
Fluoride (mg/L-¹)	0.07 ± 0.04^{a}	0.04 ± 0.01^{a}	0.04 ± 0.01^{a}	0.06 ± 0.05^{a}	0.05 ± 0.03^{a}
Chloride (mg/L-¹)	10.04 ± 7.74^{a}	38.44 ± 71.50^{a}	60.80 ± 96.01^{a}	168.07 ± 299.24^{a}	83.37 ± 130.07^{a}
Nitrite (mg/L-¹)	-	-	0.29 ± 0.33^{a}	0.57 ± 0.37^{a}	2.37 ± 3.68^{a}
Nitrate (mg/L-¹)	0.83 ± 2.03^{a}	5.76 ± 4.99^{b}	5.43 ± 5.08^{b}	3.13 ± 3.31^{ab}	1.63 ± 2.55^{ab}
Phosphate (mg/L-¹)	2.06 ± 4.42^{a}	2.69 ± 1.80^{ab}	5.55 ± 3.74^{b}	10.37 ± 7.07^{b}	8.82 ± 5.91^{b}
Sulfate (mg/L-¹)	0.58 ± 1.23^{a}	1.33 ± 0.99^{ab}	2.43 ± 1.17^{b}	3.86 ± 2.44^{b}	3.11 ± 1.71^{b}

*Values bearing same superscripts do not differ significantly (p>0.05) Source: Authors (2023)

Figure 3 – Chemicals parameters by treatment

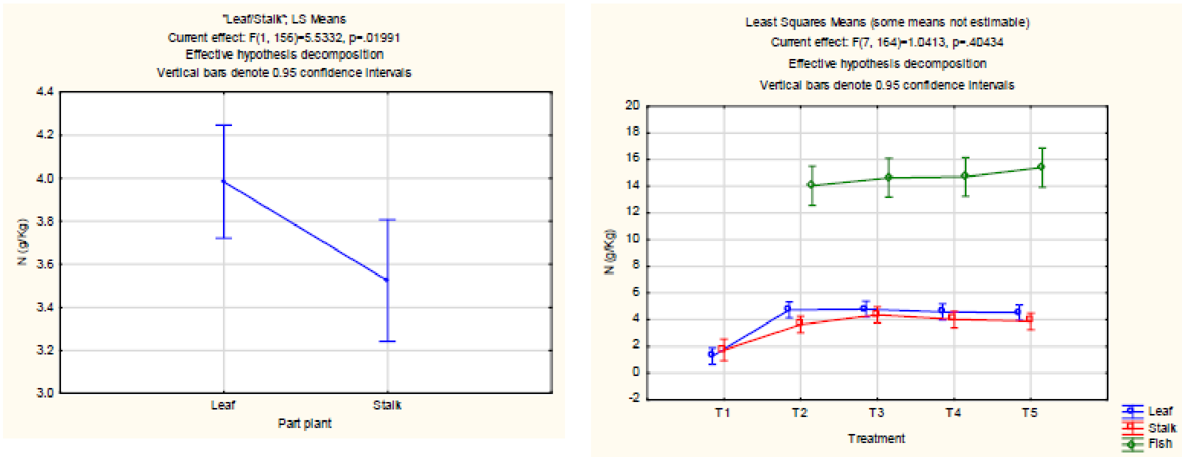


Source: Authors (2023)

3.4 Total Nitrogen

Total nitrogen analyses were performed for plants (leaves and stalks) and fish to determine if there were any differences between treatments. Differences were observed in the nitrogen content of plant parts and between treatments, but no significant differences were observed for the fish (Fig 4).

Figure 4 – Total nitrogen (g/Kg) of plant parts and fishes: (m) graph of the nitrogen content in leaves and stalk; (n) graph of the nitrogen content in the leaf, stalk and fish for treatment



(m) (n)

4 DISCUSSION

At the end of the experimental duration, the highest fish growth was observed in the lowest density compared to other treatment groups. The mean body weight (g), length (cm), weight gain (%), and length gain (%) of *A. bimaculatus* fingerlings were found to be significantly ($p<0.05$) higher in T2, followed by T3 and T4, with no differences between them, and T5 as the lowest one. The specific growth rate (% d-1) followed a similar trend as for growth parameters, showing the highest values in T2, followed by T3 and T4, and the lowest values in T5. The specific growth rate (% d-1) in T2 was significantly ($p<0.05$) higher than T3, T4, and T5, as was the protein efficiency ratio (PER). For feed conversion ratio (FCR), T2 also presented the highest values, while T3 and T4 were different but similar to T2, with no difference between them, and T5 was different from all of the others, presenting the lowest values.

Regarding the protein efficiency ratio (PER) in our experiment, the values of 1.27 and 1.06, related to T3 and T4 respectively, were statistically similar to those reported by Hundley et al. (2018) and Patil et al. (2019), where the values fluctuated from 1.25 to 1.50 and from 1.50 to 1.56 respectively, corresponding to tilapia (*Oreochromis niloticus*) growth (0.15, 0.25, and 0.5 fish L-1) for 45 days and goldfish (*Carassius auratus*) growth (0.5, 0.6, and 0.7 fish L-1) for 36 days respectively. The value for PER of the lowest density treatment, T2 was higher than that observed by the cited authors at 1.90, while for the highest density treatment, T5, the value of 0.49 demonstrates that fish growth was not efficient despite demonstrating growth.

For lemon balm performance, Manukyan and Schnitzler (2006) found that 25ºC was the best temperature for increasing lemon balm yield in the greenhouse (total 123.9 g/plant), and fresh weight varied among cultivars, with ranges between 134.0 g/plant and 266.0 g/plant (Szab'o et al., 2016). The yield of lemon balm was also affected by the growth substrate used, including wood fiber (77.1 g/plant) or sand (77.4 g/plant) (Manukyan et al. 2004). Son et al. (2021), in an experiment testing different hydroponic systems, found plant yields between 110.3–162.0 and 183.4–277.4 g/plant, similar to those of non-hydroponic cultivated lemon balm plants grown in the same greenhouse conditions. Even though lemon balm studies using aquaponics are incipient, in our study, the best treatment, T3, was 128.12 g/plant, similar to greenhouse and hydroponic conditions (Son et al. 2021), while the two treatments with the highest densities of fish, T4 and T5, demonstrated values of plant weight (g) similar to substrate conditions, at 75.01 and 63.62 respectively, and the treatment with the lowest density of fish, T2, also showed the lowest results for plant weight (g) performance. All treatments showed gains in weight and length.

The temperature and DO values showed no statistical differences between treatments, while pH demonstrated differences between treatments throughout the experiment. The control treatment, T1, and T3 were similar, above pH 6, while T2 and T5 were intermediate, and T4 was the lowest at 5.79. According to Somerville et al. (2014), the pH level of water has an impact on the biological activity of nitrifying bacteria and their ability to convert ammonia and nitrite, and the best way to ensure that plants do not suffer from deficiencies is to maintain optimum water pH (6–7), feed fish a balanced and complete diet, and use the feed rate ratio to balance the amount of fish feed to plants.

In general, the tolerance range for most plants is 5.5–7.5, and the lower range is below tolerance for fish and bacteria; most plants prefer mildly acidic conditions (Somerville et al. 2014). Even though some values of pH were below optimum values, only T4 demonstrated a difference from the control treatment as being the lowest one. Therefore, it is broadly argued that pH represents one of the largest water quality compromises present in aquaponic science (Goddek et al. 2015; Suhl et al. 2016). Maucieri et al. (2019) indicate that potassium, calcium, and magnesium are available to plants in a wide range of pH; however, the presence of other ions may interfere with their plant availability due to the formation of compounds with different grades of solubility.

At the end of the experiment, the values of the chemical parameters, sodium, fluoride, and chloride, showed no significant differences between treatments. For potassium, calcium, magnesium, and sulfate, the results obtained from T1 were significantly different from those of the other treatments, showing the lowest values. For the first parameter, the mean value for T2 was similar to T1 but also similar to T3 and T4 and different from T5, as was T1. For the other parameters, the mean values showed the same dynamic, being lower at T1, which is similar to T2 that is similar to T3, T4, and T5, but all these last three are different from T1. Somerville et al. (2014) point out that over time, even an aquaponic system that is perfectly balanced may become deficient in certain nutrients, most often iron, potassium or calcium; however, in our study both nutrients, potassium and calcium, demonstrated significant differences between treatments and the control as written above. Sodium and chloride showed high values which could be explained by the addition of sodium chloride - NaCl for preventive treatment when biometric analyses were performed at intervals of 15 days.

For fish growth, ammonia and nitrite are toxic but nitrate is comparatively harmless; for growing higher plants, nitrate is the most preferred form of nitrogen (Rakocy et al. 2006). Nitrate is the end product of nitrification and commonly the last parameter to be controlled in recirculation systems due to its relatively low toxicity (Davidson et al. 2014; Schroeder et al. 2011; van Rijn 2013). This is mostly attributed to its low permeability at the fish gill membrane (Camargo & Alonso 2006). The most commonly used nitrogen forms for plant fertilization are nitrate and ammonium; while nitrates are quickly absorbed by roots, are highly mobile inside plants and can be stored without toxic effects; ammonium can only be absorbed by plants in low quantities and cannot be stored in high quantities because it exerts toxic effects (Maucieri et al. 2019).

The results for nitrogen compounds diluted in aquaponic solutions showed significant differences between treatments. The control treatment, T1, presented the lowest values for ammonium and nitrate and also presented a null value for nitrite as did T2. For ammonium, all treatments showed differences with T3 being similar to T1 presenting the lowest values followed by T4, T2 and T5 respectively. The treatment with the highest fish density, T5 showed a critical level of ammonium which is toxic for fish. For nitrite only the three highest density treatments presented values for this nutrient showing no significant differences between them.

The dynamic of the nitrate results showed T1 as the lowest one, while T4 and T5 were higher but similar to T1, and T2 and T3 presented the highest values, having no difference between them but also having similarity to T4 and T5. Phosphorus is one of the essential elements for plant growth and can be absorbed in its ionic orthophosphate form (Prabhu et al. 2007; Resh 2013). Little is known about the dynamics of phosphorus in aquaponics (Eck et al. 2019). The solubility of phosphorus depends on pH, and a higher pH will foster the precipitation of phosphorus, thus rendering it unavailable for plants (Yildiz et al. 2017). Phosphate values showed significant differences between treatments, with T1 having the lowest values followed by T2, which was similar to

T1 and the other treatments, while T3, T4, and T5 were the highest ones, having no difference between them.

Comparing the values of nitrogen content in plant parts for treatment, only T1 had significant differences from the other treatments, and considering all treatments had proportionally the same feed offer, it is notable that lemon balm plants converted the same quantity of this nutrient, presenting similar content for this parameter but presenting different results for other plant growth parameters. Relating plant nitrogen content and nitrogen compounds in water, it is observed that the first did not correlate to the second since there was no difference between this parameter in fish-fed treatments (T2-T5).

According to Wongkiew et al. (2017), the concentration of nitrogen in both fish and plants, which in aquaponic systems comes from fish effluent, allows analyzing the absorption of this nutrient in the system. As fish excrete nitrogen in the form of ammonia, microorganisms (nitrifying bacteria) transform the nutrient so that plants absorb it as nitrate. As there are no studies that take into account growth patterns of *Astyanax bimaculatus* and lemon balm in aquaponic systems, it is important that future works consider these data on nitrogen content in each element (fish, plants, microorganisms, and water in the system) in order to calculate the nitrogen utilization efficiency rate using this conformation.

Therefore, the key to aquaponics efficiency lies in the interplay between fish density and nutrient dynamics, which directly influences plant growth and overall system productivity. Achieving the right balance between fish density and nutrient levels is essential for optimizing both fish health and plant yield. Fish density in aquaponics systems typically refers to the biomass of fish per unit volume of water. Kitaya et al. (2023) indicates that increasing the density of loach fish and lettuce plants can increase the total biological production of fish and plants. However, it will be important to control both fish and plant densities to increase nitrogen recovery in aquaponics with a high fish density.

The highest fish growth, observed at T2, was different from the highest plant growth, T3. The observed results for animal growth, where the highest values were found in the treatment with the lowest fish stocking density, T2, differ from Hundley et al. (2018), who worked with tilapia densities of 0, 0.15, 0.25, and 0.5 fish L-1 and found better results for fish and plants in the highest fish stocking density. Also, Patil et al. (2019), who worked with goldfish densities of 0.5, 0.6, and 0.7 fish L-1 found better results for plants and fish at the highest fish stocking density. Both studies were operated in media bed aquaponic systems like ours but with production of marjoram (*Origanum majorana*) and sweet basil (*Ocimum basilicum*) in the first and lemon balm in the second.

T2 likely achieved better fish growth due to the reduced nutrient input, as the smaller amounts of feed, along with leftover feed and waste, were lower compared to treatments with higher stocking densities. This is reflected in the water quality data, where T2 shows lower levels of ammonia, nitrite, and nitrate. In contrast, T3 yielded the best results for plant growth, suggesting that plants may be selective in their uptake of nutrients available in the aquatic environment.

Aquaponic studies that utilize *Astyanax bimaculatus* are scarce. Recently, Pinho et al. (2021) indicated South American fish species suitable for aquaponics, relating *A. bimaculatus* as one of them and pointing out that there is no scientific information about its production in aquaponics. Navarro et al. (2021) did not find differences in tilapia fingerlings and sweet basil growth when comparing fish stocking densities of 0.072, 0.144, and 0.216 fish L-1. In our study, we observed that the values of fish growth were inversely proportional to the highest densities while plant growth was better at T3, T4, and T5 respectively. According to Lennard (2017), if water chemistry can be matched to the requirements of the three sets of important life forms (fish, plants, and bacteria), efficiency and optimization of growth and health of all may be aspired to. Delaide et al. (2016) reported that interaction between microorganisms and dissolved organic matter present in a recirculating aquaculture system stimulates both root and shoot of plants resulting in good plant crop.

It was observed that for fish the two systems with the lowest population density, T2 and T3, presented the best performance results with no differences between them. As for plants, treatment T3 showed better results and therefore we recommend treatment T3 as ideal for replication in micro aquaponic systems coupled with substrate beds. Also, it was observed that lemon balm plants are selective in absorbing nutrients and an increase in nutrient concentration in systems did not favor greater growth for this species in studied systems as observed by Juárez-Rosete et al. (2018) on hydroponic production of oregano at different nutrient concentrations.

As the challenges within any aquaponics system are to control inputs – water, fingerlings, feed, plantlets – and their associated microbiota to maximize the benefits of organic matter and its breakdown into bioavailable forms for target organisms (Joyce et al. 2019), the main advantages of coupled aquaponics are in the most efficient use of resources such as feed for nutrient input, phosphorous, water, and energy as well as in an increase in fish welfare (Palm et al. 2019). It is believed that the aquaponic systems used and conditions were properly designed to produce *A. bimaculatus* fingerlings and lemon balm, recycling water and favoring nutrient cycling, mostly at T2 and T3.

Espinal & Matulié (2019) point out that in attached growth systems, solid forms (sand grains, stones, plastic elements) are used as substrates to retain bacteria inside the reactor and thus do not need a post-treatment solids capture step. In classical, fully recirculating aquaponic designs, one of the key design drivers is to use the main nutrient input source, fish feed, as efficiently as possible; therefore fully recirculating designs strive to supply as many of the nutrients required for plants from fish feed (Lennard 2017). The formation of biofilms was observed at all media bed units, which optimizes water treatment; but despite all fish-fed treatments (T2-T5) being fed at 4% of the gross weight of biomass, at T5 all parameters of fish performance were unsatisfactory. The main task of coupled aquaponics is the purification of aquaculture process water through integration of plants which add economic benefits when selecting suitable species like herbs, medicinal plants or ornamentals (Palm et al. 2019).

Small-scale aquaponic systems, commonly used in residential or community settings, are characterized by lower biomass densities and simpler management practices. According to Lobillo-Eguíbar et al. (2020), the adoption of such systems is often driven by values such as autonomy and the self-sufficiency of producing healthy, high-quality food—both fish and vegetables free from pesticides. These systems are relatively easy to manage and require less financial investment, making them accessible to individuals and small communities. The ecological principles of aquaponics, which encourage the development of a diverse microbial community, have been shown to benefit the health of both fish and plants. While there is ongoing discussion about the precise definition of aquaponics and the role of fish waste in nutrient delivery, studies indicate that both approaches offer benefits and can yield comparable production rates for fish and plants (Bakaluba 2023).

The current study identified some limitations in small aquaponic systems, particularly a deficiency in micronutrients. However, these systems effectively demonstrated their ability to produce both fish and plants in a complementary manner, with successful growth observed in both species, including the flowering of lemon balm. While our study did not assess the economic viability of lambari production, Castilho-Barros et al. (2023) noted that producing lambari alongside lettuce in aquaponics carries moderate economic risks. In contrast, Kodama (2016) found a high return on investment of an aquaponic system, highlighting the potential for added value by incorporating ornamental species with short growth cycles, allowing for multiple harvests per year. Furthermore, lambari production can create local employment opportunities, supporting rural development and enhancing community resilience.

Lemon balm production offers potential for financial growth, especially as the global herbal medicine market continues to expand. With increasing demand in developing countries, the market is projected to reach USD 104.78 billion by 2026, growing at a Compound Annual Growth Rate of 6.5%. This growth is driven by rising public and scientific interest in medicinal plants for primary healthcare (Bareetseng 2022). Additionally, lemon balm's relatively short growth cycle enables multiple harvests per season, which can boost overall yield and income potential.

A key advantage of small aquaponic systems is their low implementation and operational costs, making it feasible for small-scale producers to cultivate lemon balm and other species. Henriques et al. (2022) found that these low-cost recirculation systems demonstrated productivity levels comparable to conventional production methods, with no significant differences in growth patterns, biomass, or weight-length ratios. This provides small producers with increased profit opportunities, promoting activity diversification and improving family incomes.

5 CONCLUSION

Considering aquaponic systems as a sustainable manner to produce two high-value products at the same time, conformations between aquatic organisms and vegetables are key to determining economic success for farmers. Despite aquaponics being more studied on academic scales, scientific works that relate the choice of valuable species and their growth performances are interesting for producers to visualize better gains in aquaponic production. As observed in our study, the production of *Astyanax bimaculatus* fingerlings and lemon balm in a media bed aquaponic system was satisfactory, presenting animal and plant growth; the medium fish stocking densities demonstrated better results (T2 for fish; T3 for plants), which can aggregate financial feedback for producers. Considering medicinal leafy plants in aquaponics, precisely lemon balm can be an excellent choice of species and also *A. bimaculatus* fingerlings, which can be transferred to bigger fish tanks or sold to fish farmers and/or aquarium stores.

In conclusion, lambari (*Astyanax* sp.) production offers a promising opportunity for small-scale farmers looking to boost their income and enhance food security. Its adaptability and market potential make lambari farming a viable income-generating activity, especially in rural areas. Similarly, the cultivation of lemon balm (*Melissa officinalis*) provides small-scale farmers with a valuable chance to increase their earnings and improve their livelihoods. With growing market demand, relatively straightforward cultivation requirements, and potential for high returns, lemon balm represents a sustainable crop that can contribute to rural development.

Experiments that consider medicinal plants in aquaponics, especially lemon balm, should be stimulated to determine possible growth differences between hydroponic units, as well as mineral content, antioxidative capacities, and phenolic compounds.

ACKNOWLEDGEMENTS

We would like to thank the academic group AcquaUnB and the Environmental Sciences Postgraduate Program at the University of Brasília (PPGCA/UnB), for their support; Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA Cerrados, Water Chemistry Laboratory (specially Daphne Muniz), EMBRAPA Hortaliças (specially Juscimar Silva) for assistance on chemical analysis and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES for funding.

REFERENCES

Alves, A. S. (2017). *Produção e qualidade de Melissa offinalis L. em diferentes condições de cultivo* (Dissertação Mestrado em Produção Vegetal). Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil.

Assis, R. M. A., Carneiro, J. J., Medeiros, A. P. R., Carvalho, A. A., Cunha Honorato, A., Carneiro, M. A. C., Bertolucci, S. K. V., & Pinto, J. E. B. P. (2020). Arbuscular mycorrhizal fungi and organic manure enhance growth and accumulation of citral, total phenols, and flavonoids in *Melissa officinalis* L. *Ind. Crop. Prod.*, *158*, 112981. doi: 10.1016/j.indcrop.2020.112981

Bakaluba, B. D. (2023). *Nutrient Cycling and Water Quality Management in Aquaponics*. Hochschule Rhein-Waal. doi: 10.13140/RG.2.2.17166.13128

Bareetseng, S. (2022). The Worldwide Herbal Market: Trends and Opportunities. *J. Biomed. Res. Environ. Sci*. *3*(5), 575-584. doi: 10.37871/jbres1482

Camargo, J. A., & Alonso, A. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. *Environ. Int*., *32*, 831–849. doi: 10.1016/j.envint.2006.05.002

Carnat, A., Fraisse, D., & Lamaison, J. L. (1998). The aromatic and polyphenolic composition of lemon balm (*Melissa officinalis* L. subsp. officinalis) tea. *Pharmaceutics Acta Helvetiae*, *72*, 301-305. doi: 10.1016/S0031-6865(97)00026-5

Castilho-Barros, L., Galan, G. D., Prieto, R. F., Azedo, M. R., Barbieri, E., & Henriques, M. B. (2023). Financial feasibility of a small-scale urban aquaponic system in Brazil: production of lambari rosa (Astyanax lacustris) with lettuce (Lactuca sativa). *Research Square Platform LLC*. doi: 10.21203/rs.3.rs-2720389/v1

Channa, A. A., Munir, K., Hansen, M., & Tariq, M. F. (2024). Optimisation of Small-Scale Aquaponics Systems Using Artificial Intelligence and the IoT: Current Status, Challenges, and Opportunities. *Encyclopedia, 4,* 313–336. doi: 10.3390/encyclopedia4010023

Davidson, J., Good, C., Welsh, C., & Summerfelt, S. (2014). Comparing the effects of high vs. low nitrate on the health, performance, and welfare of juvenile rainbow trout Oncorhynchus mykiss within water recirculating aquaculture systems. *Aquac. Eng.*, *59*, 30–40. doi: 10.1016/j.aquaeng.2014.01.003

Delaide, B., Goddek, S., Gott, J., Soyeurt, H., & Jijakli, M. (2016). Lettuce (Lactuca sativa L. var. Sucrine) growth performance in complemented aquaponic solution outperforms hydroponics. *Water*, *8*, 467. doi: 10.3390/w8100467

Eck, M. (2017). *Taxonomic characterization of bacteria communities from water of diversified aquaponic systems* (Thesis for the partial fulfillment of a Masters Degree). Université de Liège, Liège, Bélgica.

Espinal, C. A., & Matulié, D. (2019). Recirculating Aquaculture Technologies. In Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (org). *Aquaponics Food Production Systems. Combined Aquaculture and Hydroponic Production Technologies for the Future (*pp. 35- 76). SpringerOpen. doi: 10.1007/978-3-030-15943-6

Food and Agriculture Organization of the United Nations (FAO). (2017). *The future of food and agriculture: Trends and challenges*. FAO.

Food and Agriculture Organization of the United Nations (FAO). *FAO's hole in water*. FAO. Recovered from: https://www.fao.org/water/en/

Fernandes, I. M., Bastos, Y. F., Barreto, D. S., Lourenço, L. S., & Penha, J. M. (2017). The efficacy of clove oil as an anaesthetic and in euthanasia procedure for small-sized tropical fishes. *Braz. J. Biol., 77*(3), 444-450. doi: 10.1590/1519-6984.15015

Galvani, F., & Gaertner, E. (2006). Adequação da Metodologia Kjeldahl para determinação de Nitrogênio Total e Proteína Bruta. (63rd ed). Corumbá: Circular Técnica, Embrapa Pantanal.

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K., Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability*, *7*, 4199–4224. doi: 10.3390/su7044199

Gonçalves, F. H. A. S. B. (2017). *Sustentabilidade dos sistemas de produção do lambari-do-rabo-amarelo*. (PhD thesis). Centro de Aquicultura, Universidade Estadual Paulista. Jaboticabal, SP, Brasil.

Hartmann, H. T., Kester, D. E., Davies Jr, F. T., Geneve, R. L., & Wilson, S. E. (2018). Plant propagation: principles and practices. (9th ed). New Jersey: Prentice Hall.

Henriques, M. B., Castilho-Barros, L., Souza, M. R., Barbieri, E., Silva, N. J. R., Nunes, F. A. A., & Sanches, E. G. (2022). Is the small-scale aquaculture of lambari *Deuterodon iguape* (Eigenmann 1907) for live bait in recirculating systems economically profitable? *Aquaculture, 546, 737335.* doi: 10.1016/j.aquaculture.2021.737335

Hundley, G. C., Ribeiro Filho, O. P., Navarro, F. K. S. P., & Navarro, R. D. (2018). Integration of Nile tilapia (Oreochromis niloticus L.) production Origanum majorana L. and Ocimum basilicum L. using aquaponics technology. *Acta Scient Tech*, *40*, 35460. doi: 10.4025/actascitechnol.v40i1.35460

IBGE. (2021). *Aquaculture statistics: Growth and market analysis in Brazil*. Brazilian Institute of Geography and Statistics.

Ibrahim, L. A., Shaghaleh, H., El-Kassar, G. M., Abu-Hashim, M., Elsadek, E. A., & Hamoud, Y. A. (2023). Aquaponics: A Sustainable Path to Food Sovereignty and Enhanced Water Use Efficiency. *Water, 15*(24), 4310. doi: 10.3390/w15244310

Joyce, A., Goddek, S., Kotzen, B., & Wuertz, S. (2019). Aquaponics: Closing the cycle on limited water, land and nutrient resources. In Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (org). *Aquaponics Food Production Systems. Combined Aquaculture and Hydroponic Production Technologies for the Future* (pp. 19-34). SpringerOpen. doi: 10.1007/978-3-030-15943-6

Juaréz-Rosete, C. R., Aguilar-Castillo, J. A., Aburto-Gonzáles, C. A., & Alejo-Santiago, G. (2018). Biomass production, nutritional requirement of nitrogen, phosphorus and potassium, and concentration of the nutrient solution in oregano. *Revista Chapingo Serie Horticultura*, *25*(1), 17-28. doi: 10.5154/r.rchsh.2018.02.006

Kennedy, D. O., Scholey, A. B., Tildesley, N. T., Perry, E. K., & Wesnes, K. A. (2002). Modulation of mood and cognitive performance following acute administration of Melissa officinalis (lemon balm). *Pharmacol Biochem Behav. 72*(4), 953-64. doi: 10.1016/s0091-3057(02)00777-3.

Khalid, A. K., Hu, W., & Cai, W. (2008). The Effects of Harvesting and Different Drying Methods on the Essential Oil Composition of Lemon Balm (Melissa officinalis L.). *Journal of Essential Oil Bearing Plants*, *11*(4), 342-349. doi: 10.1080/0972060X.2008.10643639

Kitaya, Y., Kawamoto, T., Endo, R., & Shibuya, T. (2023). Effect of fish density on biological production in aquaponics combining lettuce hydroponics and loach aquaculture for controlled ecological life support systems in space. *Frontiers in Astronomy and Space Sciences, 10*. doi: 10.3389/fspas.2023.1197402

Kjeldahl, J. (1883). A new method for the determination of nitrogen in organic matter. *Analy Bioanaly Chem, 22*, 366-382. doi: 10.1007/BF01338151

Kodama, G. (2016). Viabilidade Financeira em Sistema de Aquaponia (Dissertação de Mestrado). Universidade de Brasília, Brasília, DF, Brasil.

Lennard, W. (2017). *Commercial aquaponic systems: integrating recirculating fish culture with hydroponic plant production*. Wilson Lennard.

Lobillo-Eguíbar, J., Fernández-Cabanás, V. M., Bermejo, L. A., & Pérz-Urrestarazu, L. (2020). Economic Sustainability of Small-Scale Aquaponic Systems for Food Self-Production. *Agronomy*, *10*(10), 1468. doi: 10.3390/agronomy10101468

Lopes, M. C., Silva, N. J. R., Casarini, L. M., Gonçalves, F. H. A. S. B., & Henriques, M. B. (2013). Desova Induzida do Lambari Deuterodon iguape com Extrato Hipofisário de Carpa. *Tropic. J Fish. Aquat. Scie*., *13*(1), 9-13. doi: 10.17080/1676-5664/btcc.v13n1p9-13

Manukyan, A., Heuberger, H., & Schnitzler, W. (2004). Yield and quality of some herbs of the Lamiaceae family under soilless greenhouse production. *J. Appl. Bot. Food Qual., 78*, 193– 199.

Manukyan, A., & Schnitzler, W. (2006). Influence of air temperature on productivity and quality of some medicinal plants under controlled environment conditions. *Eur. J. Hortic. Sci., 71*, 26–35. Recovered from: https://www.semanticscholar.org/paper/Influence-of-Air-Temperature-on-Productivity-and-of-Manukyan-Schnitzler/e4321d4f7b687ccab420ea3a5214b369e903055c

Masiero, M. A., Viana, C. M. S. S., Lupepsa, C. T., Silva, F. R., Almeida, G. M. C., Tombolato, J. P., Carolino, K., Silva, R. Q., & Lima, D. M. (2021). Propagação vegetativa de *Melissa officinalis* L. por estaquia. *Biodiversidade, 20*(1), 122-128. Recovered from: https://periodicoscientificos.ufmt.br/ojs/index.php/biodiversidade/article/view/11962

Maucieri, C., Nicoletto, C., Os, E. van, Anseeuw, D., Havermaet, R. van, & Junge, R. (2019). Hydroponic Technologies. In Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (org). *Aquaponics Food Production Systems. Combined Aquaculture and Hydroponic Production Technologies for the Future.* (pp. 77-110). SpringerOpen. doi: 10.1007/978-3-030-15943-6

Moradkhani, H., Sargsyan, E., Bibak, H., Naseri, B., Sadat-Hosseini, M., Fayazi-Barjin, A., & Meftahizade, H. (2010). *Melissa officinalis* L., a valuable medicine plant: A review. *Journal of Medicinal Plants Research, 4*(25), 2753-2759. Recovered from: http://www.academicjournals.org/JMPR

Navarro, R. D., Corrêa, B. R. S., Hundley, G. C., & Kodama, G. (2021). Growth of fingerlings in different stocking densities in tropical aquaponic system of basil production. *Ciência e Natura*, *43*, e95. doi: 10.5902/2179460X63222

Obirikorang, K. A., Sekey, W., Gyampoh, B. A., Ashiabor, G., & Asante, W. (2021) Aquaponics for Improved Food Security in Africa: A Review. *Front. Sustain. Food Syst., 5*, 705549. doi: 10.3389/fsufs.2021.705549

Palm, H. W., Knaus, U., Appelbaum, S., & Strauch, S. M. (2019). Coupled Aquaponics Systems. In Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (org). *Aquaponics Food Production Systems. Combined Aquaculture and Hydroponic Production Technologies for the Future.* (pp. 162-199). SpringerOpen. doi: 10.1007/978-3-030-15943-6

Parvin, S., Reza, A., S. das, Miah, M. M. U., & Karim, S. (2023). Potential Role and International Trade ofMedicinal and Aromatic Plants in the World. *European Journal of Agriculture and Food Sciences*, *5*(5), 89–99. doi: 10.24018/ejfood.2023.5.5.701

Patil, P. A., Dube, K., Verma, A. K., Chadha, N. K., Sundaray, J. K., & Jayasankar, P. (2019). Growth perfoemance of goldfish, Carassius auratus and basil, Ocimum basilicum in media bed aquaponics. *Indian J. Fish*, *66*(1), 112-118. doi: 10.21077/ijf2019.66.1.78353-15

Patora, J., & Klimek, B. (2002). Flavonoids from lemon balm (Melissa officinalis L., Lamiaceae). *Acta Pol. Pharm*., *59*(2), 139-43. Recovered from: https://pubmed.ncbi.nlm.nih.gov/12365606/

Peh, J. H., & Azra, M. N. (2025). A global review of ornamental fish and shellfish research. *Aquaculture*, *596*(1), 741719. doi: 10.1016/j.aquaculture.2024.741719

Pinho, S. M., David, L. H., Garcia, F., Keesman, K. J., Portella, M. C., & Goddek, S. (2021). South American fish species suitable for aquaponics: a review. *Intern Aquacult*, *29*, 1427-1449. doi: 10.1007/s10499-021-00674-w

Prabhu, P. A. J., Schrama, J. W., & Kaushik, S. J. (2016). Mineral requirements of fish: a systematic review. *Rev. Aquacult*, *8*, 172–219. doi: 10.1111/raq.12090

Rakocy, J. E., Masser, M. P., & Losordo, T. M. (2006). *Recirculating aquaculture tank production systems: aquaponics – integrating fish and plant culture* (454th ed). USA: SRAC Publication, Southern Regional Aquaculture Center.

Resh, H. M. (2013). *Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower* (7th ed). Boca Raton: CRC Press.

Sabry, R. M., Salama, A., & Wahba, H. E. (2023). Growth and quality of lemon balm (*Melissa officinalis*) as influenced by various plant extracts. *Journal of Applied Horticulture*, *24*(03), 375-380. doi: 10.37855/jah.2022.v24i03.68

Schroeder, J. P., Croot, P. L., Dewitz, B. von, Waller, U., & Hanel, R. (2011). Potential and limitations of ozone for the removal of ammonia, nitrite, and yellow substances in marine recirculating aquaculture systems*. Aquac. Eng., 45*, 35–41. doi: 10.1016/j.aquaeng.2011.06.001

Silva, N. J. R., Lopes, M. C., Fernandes, J. B. K., & Henriques, M. B. (2011). Caracterização dos sistemas de criação e da cadeia produtiva do Lambari no Estado de São Paulo. *Info. Econ., 41,* 17-28. Recovered from: file:///D:/sei%20l%C3%A1/lambari_cadeia_produtiva2011.pdf

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). *Small-scale aquaponic food production: integrated fish and plant farming.* (n. 589). FAO Fisheries and Aquaculture, Technical Paper.

Son, Y. J., Park, J. E., Kim, J., Yoo, G., & Nho, C. W. (2021). The changes in growth parameters, qualities, and chemical constituents of lemon balm (*Melissa officinalis* L.) cultivated in three different hydroponic systems*. Ind. Crops Prod.*, *163*, 113313. doi: 10.1016/j.indcrop.2021.113313

Sorensen, J. M. (2000). Melissa Officinalis. *International Journal of Aromatherapy*, *10*(1-2), 7-15. doi: 10.1016/S0962-4562(00)80004-1

Suhl, J., Dannehl, D., Kloas, W., Baganz, D., Jobs, S., Scheibe, G., & Schmidt, U. (2016). Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. *Agricultural Water Management*, *178*, 335–344. doi: 10.1016/j.agwat.2016.10.013.

Szab'o, K., Malekzadeh, M., Rad'acsi, P., Lad'anyi, M., Rajh'art, P., Inotai, K., Tavaszi- S'arosi, S., & N´Emeth, E. (2016). Could the variety influence the quantitative and qualitative outcome of lemon balm production? *Ind. Crops Prod., 83*, 710–716. doi: 10.1016/j.indcrop.2015.12.027

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2021). *World Water Development Report: Valuing Water*. UNESCO.

Rijin, J. van. (2013). Waste treatment in recirculating aquaculture systems. *Aquac. Eng., 53*, 49–56. doi: 10.1016/j.aquaeng.2012.11.010

Venskutonis, R., Gruzdienè, Tirzite, D., & Tirzitis, G. (2005). Assessment of antioxidant activity of plant extracts by different methods. *Acta Horticulture, 677*(677), 99-107. doi: 10.17660/ActaHortic.2005.677.13

Viegas, R. M., França, C. L., Castro, J. S., Castro, J. J. P., Santana, T. C., Costa-Lima, M. P. G., Carvalho Neta, R. N. F., Carneiro, C. R. P., & Teixeira, E. G. (2020). Eugenol as an efficient anesthetic for neotropical fish *Prochilodus nigricans* (Teleostei, Prochilodontidae). *Arq. Bras. Med. Vet. Zootec., 72(*5), 1813-1820. doi: 10.1590/1678-4162-11866

Yep, B., & Zheng, Y. (2019). Aquaponic trends and challenges: A review. *J. Clean. Prod*., *228*, 1586–1599. doi: 10.1016/j.jclepro.2019.04.290

Yildiz, H. Y., Robaina, L., Pirhonen, J., Mente, E., Domínguez, D., & Parisi, G. (2017). Fish welfare in aquaponics system: its relation to water quality with an emphasis on feed and faeces-a review. *Water*, *9*, 13. doi: 10.3390/w9010013

Wongkiew, S., Hu, Z., Chandran, K., Lee, J. W., & Khanal, S. K. (2017). Nitrogen transformations in aquaponic systems: A review. *Aqua. Eng., 76*, 1-43. doi:10.1016/j.aquaeng.2017.01.004

Authorship contributions

1 – Bernardo Ramos Simões Corrêa

Biologist, PhD in Enviromental Sciences at University of Brasília - UnB
https://orcid.org/0000-0003-1625-1843 • bernersc@hotmail.com
Contribution: Research creator, Writing – original draft, Data collection

2 – Rodrigo Diana Navarro

Post-doctorate in Physiology of freshwater fish reproduction at the Federal University of Lavras (2010).
https://orcid.org/0000-0001-8897-7163 • navarrounb@gmail.com
Contribution: Research creator

How to quote this article

Corrêa, B. R. S., & Navarro, R. D. (2025). Tropical aquaponic production of lemon balm, *Melissa officinalis*, using different *Astyanax bimaculatus* fingerling stocking densities. *Revista Ciencia e Natura*, 47, e74160. doi: 10.5902/2179460X74160.