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Article

Tropical Aquaponic Production of Medicinal Plants in Association with Goldfish

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ABSTRACT

Aquaponics is an emerging technology that synergistically combines aquaculture and hydroponic production through nutrient cycling and water recycling. As aquaponics grows exponentially, studies that evaluate the technique by testing different species in these systems make this choice fundamental to result in a high productivity and profitability. Ornamental fish, as well as medicinal plants, are interesting options for a more in-depth analysis of aquaponic systems. In this context, the objective was to analyze the performance of four plant species: boldu chilanum, *Peumus boldus*; peppermint, *Mentha* x *piperita*; Brazilian joyweed, *Alternanthera brasiliana*; and oregano, *Origanum vulgare*, as well as the growth of goldfish, *Carassius auratus*, and physicochemical aspects of water quality in identical aquaponic systems installed in a greenhouse during 91 days of cultivation. The experimental design consisted in four treatments and four replications, using in all treatments a density of 21 fish.310L and four seedlings, in cuttings, of each plant species studied. The vegetable cultivation systems were composed of expanded clay sediments in a 0.25m² planters, using a density of 16 plants.m², repeated, each treatment, in four aquaponic systems, totaling 16 aquaponic systems analyzed. The results showed that, for the parameters of weight and height, of the four plant species studied, only oregano did not develop as expected, while boldu chilanum, peppermint and Brazilian joyweed showed a representative increase in the analyzed parameters. The goldfish also showed representative increase for weight, total and standard length in all treatments. The water quality parameters analyzed did not showed differences between treatments and were within the range recommended by reference authors, as well as for the well-being of the goldfish. The systems have demonstrated efficiency in vegetative and animal growth, and can help to add value to products from aquaponics, corroborating the evolution of technology.

Keywords: aquaponic system; closed system; nutrient cycling; recirculation.

RESUMO

A aquaponia é uma tecnologia emergente que alia sinergicamente a produção aquícola e hidropônica, através da ciclagem de nutrientes e reciclagem de água. Como a aquaponia cresce exponencialmente, estudos que avaliam a técnica testando diferentes espécies nesses sistemas torna essa escolha fundamental para resultar em alta produtividade e lucratividade. Os peixes ornamentais, assim como as plantas medicinais são opções interessantes para uma análise mais aprofundada nos sistemas aquapônicos. Objetivou-se, nesse contexto, analisar o desempenho de quatro espécies vegetais: boldo do Chile, *Peumus boldus*; menta, *Mentha* x *piperita*; terramicina, *Alternanthera brasiliana;* e orégano, *Origanum vulgare*, assim como o crescimento de exemplares de goldfish, *Carassius auratus,* e aspectos físico-químicos da qualidade de água em sistemas aquapônicos idênticos instalados em estufa durante 91 dias de cultivo. O delineamento experimental foi composto de quatro tratamentos e quatro repetições, utilizando em todos os tratamentos densidade de 21 peixes.310L e quatro mudas, em estaca, de cada espécie vegetal estudada. Os sistemas de cultivo vegetal foram compostos por sedimentos de argila expandida em jardineiras de 0,25m², utilizando densidade de 16 plantas.m², repetidos, cada tratamento, em quatro sistemas aquapônicos, totalizando 16 sistemas aquapônicos analisados. Os resultados demonstraram que, para os parâmetros de peso e altura, das quatro espécies vegetais estudadas, apenas o orégano não se desenvolveu como o esperado, enquanto o boldo do Chile, menta e terramicina, apresentaram aumento representativo dos parâmetros analisados. O goldfish também demonstrou aumento significativo para o peso, comprimento total e comprimento padrão em todos os tratamentos. Os parâmetros de qualidade de água analisados não demonstraram diferenças estatísticas entre os tratamentos e estiveram dentro da faixa preconizada por autores de referência, assim como para o bem-estar dos goldfish. Os sistemas demonstraram eficiência no crescimento vegetativo e animal, podendo auxiliar a agregação de valor dos produtos oriundos da aquaponia corroborando com a evolução da tecnologia.

Palavras-chave: sistema aquapônico; sistema fechado; ciclagem de nutrientes; recirculação.

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1. Introduction

Aquaponics is an alternative to produce food with less impact on the environment through characteristics that refer to sustainability, such as the implementation of small family systems, the cycling of nutrients and the recycling of water resources (Diver 2006; Rakocy et al. 2006; Love et al. 2015). This integration allows plants to use nutrients from fish farming water, improving water quality, which can be reused in fish production (Hundley & Navarro 2013; Hundley et al. 2013; 2018; Kodama et al. 2019; Navarro et al. 2021).

Production systems that minimize impacts on the environment are the scientific-technological basis for a sustainable development project and aquaponics, as a system of low water consumption and nutrient reuse, can help to promote agroecological principles and the use of social and appropriate technologies (Corrêa et al. 2016). Aquaponics is an emerging food production technology that has the ability to condense and compress production into spaces and places that would not normally be used to grow food (Goddek et al. 2019), such as rooftops, abandoned industrial sites, and generally non-arable or contaminated areas (Reinhardt et al. 2019) and thus avoiding deforestation.

Aquaponic systems exist for different uses: personal or hobby use, for developing communities, as a teaching tool in science education, or as a means of increasing food production in urban settings (Love et al. 2015). However, in addition to being made up of different vegetable cultivation systems, such as: cultivation in pipes, cultivation in media beds or in flotation (Sommervile et al. 2014) and the scale of production determines whether the system is micro, small, semi-commercial or commercial (Palm et al. 2018).

The production of ornamental fish is one of the most profitable in fish farming and the success is mainly due to the high individual values that many species reach in the market, being sold per unit and not per kilogram, raising their price (Pessoa 2009). Ornamental fish are commonly associated with small, colorful species with beautiful and elegant shapes, such as goldfish, *Carassius auratus* (Linnaeus, 1758), Siamese fighting fish, *Betta splendens* Regan, 1910 and guppy, *Poecilia reticulate* Peters, 1859, considered aquarism icons with great popularity and acceptance by its practitioners around the world, however, there are a number of fish species that are not so small and that do not have any, or even none, of these characteristics (Ribeiro et al. 2010).

The goldfish is one of the most commercialized and well-known ornamental fish in the world (Rosa et al. 1994; Lima et al. 2001; Lima 2003) and according to Froese & Pauly (2022), they reach an average of 15 cm. The ideal water conditions for maintaining animal welfare varies from 15 to 24°C the temperature and the pH can be neutral or slightly alkaline. The commercialization potential of goldfish is commonly known, but some studies (Yin et al. 2014; Mohammad et al. 2018) seek to test profitability in different production systems.

Medicinal plants have been used by man since the beginning of his history and long before the emergence of writing, humanity already used herbs for medicinal purposes (Barata 2005; Toscano Rico 2011). Currently, medicinal plants are used by a large part of the world population, as an alternative medicinal resource for the treatment of various diseases, since in many communities, they represent a more accessible resource in relation to allopathic medicines (Bevilacqua 2010). Another aspect that should be highlighted is that the plant only has medicinal value when used correctly, due to the risk of intoxication and emergence of several side effects, therefore, studies related to plants in alternative medicine have deserved increasing attention, due to the successive information and clarifications they provide to science (Carneiro et al. 2014).

The Boldu chilanum, *Peumus boldus* Molina, is a tree specie, belonging to the Monimiaceae family and native to the central and southern regions of Chile, where it occurs abundantly. Its leaves are used in folk medicine to treat digestive and liver problems, and pharmacological studies found mostly describe the activities observed for the alkaloid boldine, described as the main component of boldu tea (Ruiz et al. 2008).

Peppermint, *Mentha* x *piperita* L., is among the most popular tea ingredients, having medicinal actions on biliary disorders, dyspepsia, enteritis, flatulence, and intestinal spasms (Mckay & Blumberg 2006). Also, the species is a source of one of the most popular essential oils, with several applications in the food, cosmetic and pharmaceutical industries (Costa et al. 2012).

In folk medicine Brazilian joyweed, *Alternanthera brasiliana* (L.) Kuntze, is widely used in the treatment of several pathologies, and its anti-inflammatory and analgesic action, as well as an inhibitory activity against the herpes simplex virus, has been proven (Delaporte et al. 2002). Grenand et al. (1987) found that Guyana Indians use the leaves of *A. brasiliana* as an astringent and antidiarrheal, while the macerate from the plant is used against constipation.

Oregano, *Origanum vulgare* L., an aromatic and medicinal plant is considered a tonic plant and has a great diversity of medicinal properties, with the digestive and expectorant properties being the most emphasized (Clevely & Richmond 1998). Oregano has been recognized as effective against whooping cough in children aged 2 to 12 years, and in adults its ability to calm the violent coughs accompanied by bronchorrhea and, also, in the elderly, it was found that this plant calmed the attacks of strenuous coughs, followed by flu and bronchial catarrh (Pires & Delgado 2013), been used by peasants in infusions and inhalations (Lientaghi 2002).

Knowing that, in addition to some ornamental fish tolerate cultivation in low quality waters (Santos et al. 2015), studies that use medicinal plant species in aquaponic systems are scarce, as well as those that use species of ornamental interest (Svidov et al. 2005; Bakiu et al. 2014; Palm et al. 2019; Abdel-Rahim et al. 2019; Nuwansi et al. 2019; Bakiu et al. 2019; Salama et al. 2020). However, aquaponics grows exponentially and the productivity of both fish and plants follows this growth in line with the technological evolution of these systems and all the potential of these systems must be reported. Since there is a large number of reference works on the production of plant species for food, it is necessary to analyze these systems for the production of species of medicinal interest.

Also, the production of ornamental fish can add greater sales value to fish from aquaponic production, allowing greater economic sustainability to the system. Therefore, it becomes evident the need to analyze the performance of medicinal plant species and ornamental fish in aquaponic systems, economically enhancing and valuing aquaponic production.

The present study aimed to use the experimental technique in aquaponics to analyze the performance of ornamental goldfish in association with four medicinal plants, boldu chilanum, peppermint, Brazilian joyweed and oregano, in addition to the water quality in micro identical aquaponic systems of sediment filled with expanded clay.

2. Methodology

The experiment was carried out between 18/04/2019 to 17/07/2019, totaling 91 days of cultivation, in 16 small scale aquaponic systems installed in a greenhouse at the Sustainable Aquaculture Center of the University of Brasília, localized in the Água Limpa Farm, Distrito Federal, Cerrado Biome, Brazil. The climate in the region is tropical with a dry season, type Aw in the Köppen-Geiger climate classification, with temperatures average always above 18º C and annual rainfall around 1,540 millimeters, concentrated between October and April.

The aquaponic units are made up of 310L volume polypropylene water tanks for fish production, filled until 300L, and 0.25 m² 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 experimental design was completely randomized and consisted of four treatments being differentiated only by plant species and four replications of each treatment, totaling sixteen aquaponic units. The distribution of the species in the systems was random throughout the four rows of four aquaponic systems.

For animal culture were used goldfish, *Carassius auratus*, juveniles which were already being bred at the Sustainable Aquaculture Center and the matrices were acquired from a supplier. The density was established at 21 fish.310L. The fish were fed according to what is recommended by the literature (Souto et al. 2013), with supplementary fish food (Acqualine®, 1.7mm) containing 46% of protein. For the planting of seedlings were inserted four seedlings of each species per planter so, for each plant species, 16 individuals were allocated in total, totaling 64 plants throughout the experiment.

In vegetable cultivation, the species boldu chilanum, *Peumus boldus*, peppermint, *Mentha* x *piperita*, Brazilian joyweed, *Alternanthera brasiliana*, and oregano, *Origanum vulgare* were used. The seedlings were acquired from plants there were in a mixture with soil and substrate, planted in normal environmental conditions with approximately 6 months older and pricked for installation in planters, in the aquaponic system.

For animal growth analysis biometrics were performed, at the beginning and the end of the experiment, considering parameters of weight (g), using a precision electronic digital scale (B-max® - SF-400) and total length (cm) and standard length (cm), using a tape measure. For plant growth analysis were evaluated the parameters of weight (g), using a precision electronic digital scale (B-max® - SF-400), height (cm), using a tape measure and number of leaves.

Total Nitrogen analyses were performed using the Kjeldahl method (1883), with adaptations (Galvani & Gaertner, 2006). In terms of water quality, the parameters of temperature (°C), pH and dissolved oxygen concentration (mg/L) were measured weekly using water quality probes (Hanna® - HI 9813-6; Alfakit® - AT – 160). Also, ion analyzes were performed to determine the cation ($NH4^+$ and anions ($NO2^-$, $NO3^-$ and $PO43^{-)}$ using the ion chromatograph (Methrohm®, model 761 Compact IC). Metrosep C2 ion exchange solution and as eluent a buffer solution of 4.0 mM tartaric acid and 0.75 mM dipicolinic acid (2,6-pyridinedicarboxylic acid). of 3.2 mM sodium carbonate and 1.0 mM sodium hydrogen carbonate and a suppressor solution of 100 mM sulfuric acid used in the ion suppression branch, parallel to ultrapure water, with a pre-set gradient of 50% (water/acid).

Comparative statistical analyzes of the biometric performances for animals and plants, and of the water quality were performed between the treatments using MaxStat® Lite version 3.60 and Statistica version 10 (Statsoft®) softwares. The analyses were carried out by one-way anova test, repeated measures anova, t-test, factorial anova test and Tukey test, with a significance index set at 5%.

3. Results

3.1 Water Quality

The physical and chemical water parameters did not showed significant differences between treatments (Table 1 and Figure 1). Also, the ions and cations water analysis did not show significant differences between the treatments (Table 2 and Figure 2).

Table 1. Results of the averages of physical and chemical water parameters by treatments (plant species).

Parameter/Treatment	Boldu chilanum	Peppermint	Brazilian joyweed	Oregano	F	p	df
DO (mg/L)	8.501[a]±1.274	8.388[a]±0.725	8.466[a]±0.726	8.384[a]±0.707	0.068	0.9769	63
Temperature (ºC)	22.881[a]±3.191	22.912[a]±3.356	22.944[a]±3.211	22.738[a]±3.269	0.013	0.9981	63
pH	6.462 [a]±0.328	6.431[a]±0.233	6.331[a]±0.239	6.544[a]±0.333	1.498	0.2242	63

Means followed by different letters between the lines of each treatment differ at 5% probability by the Tukey test.

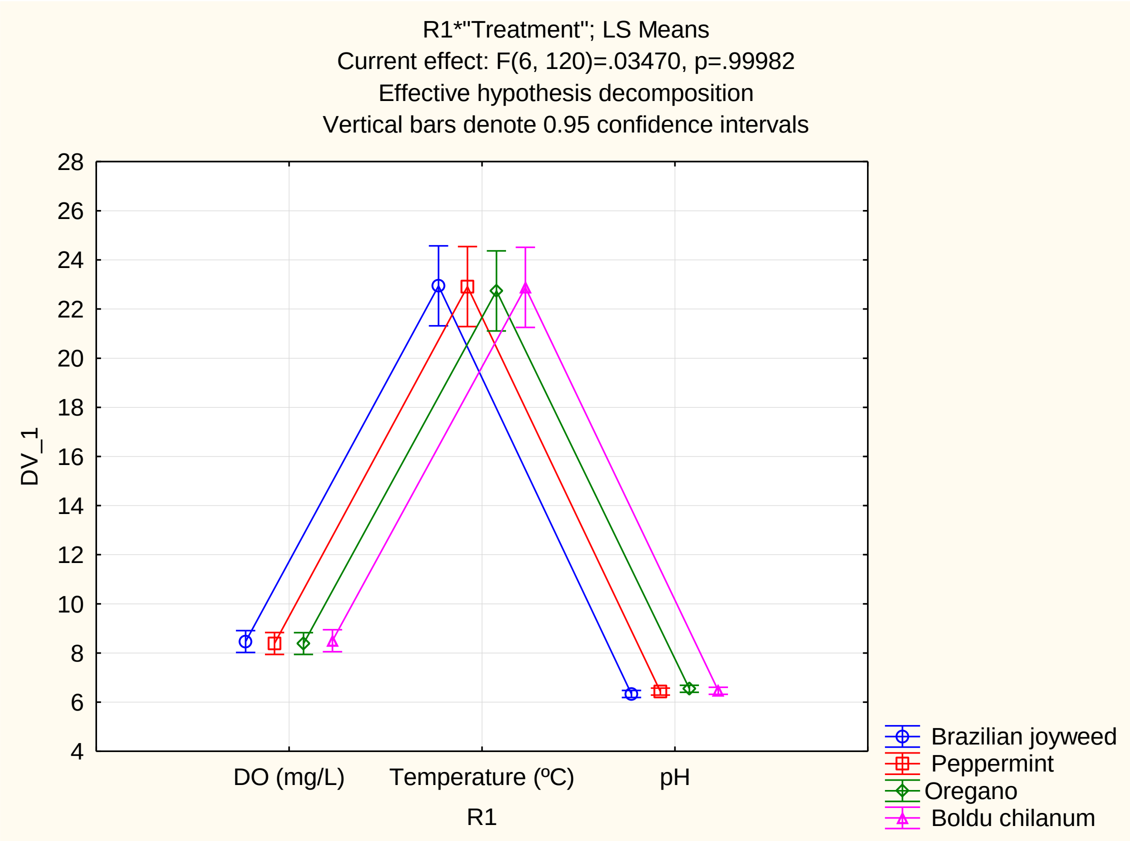

Figure 1. Averages of physical and chemical water parameters by treatment.

Table 2. Results of the averages of ions and cations parameters by treatment (plant species).

Parameter/Treatment	Boldu chilanum	Peppermint	Brazilian joyweed	Oregano	F	p	df
Ammonium (mg/L)	0.088[a]±0.054	0.118[a]±0.091	0.087[a]±0.049	0.144[a]±0.097	0.926	0.4439	26
Nitrite (mg/L)	0.058 [a]±0.129	0.053 [a]±0.101	0.064 [a]±0.124	0.009 [a]±0.025	0.487	0.6944	26
Nitrate (mg/L)	2.975 [a]±1.16	4.206 [a]±7.287	3.113 [a]±3.65	1.274 [a]±1.211	0.643	0.595	26
Phosphate (mg/L)	10.5517 [a]±6.162	6.718 [a]±7.081	5.424 [a]±2.988	3.377 [a]±2.575	2.439	0.0902	26

Means followed by different letters between the lines of each treatment differ at 5% probability by the Tukey test.

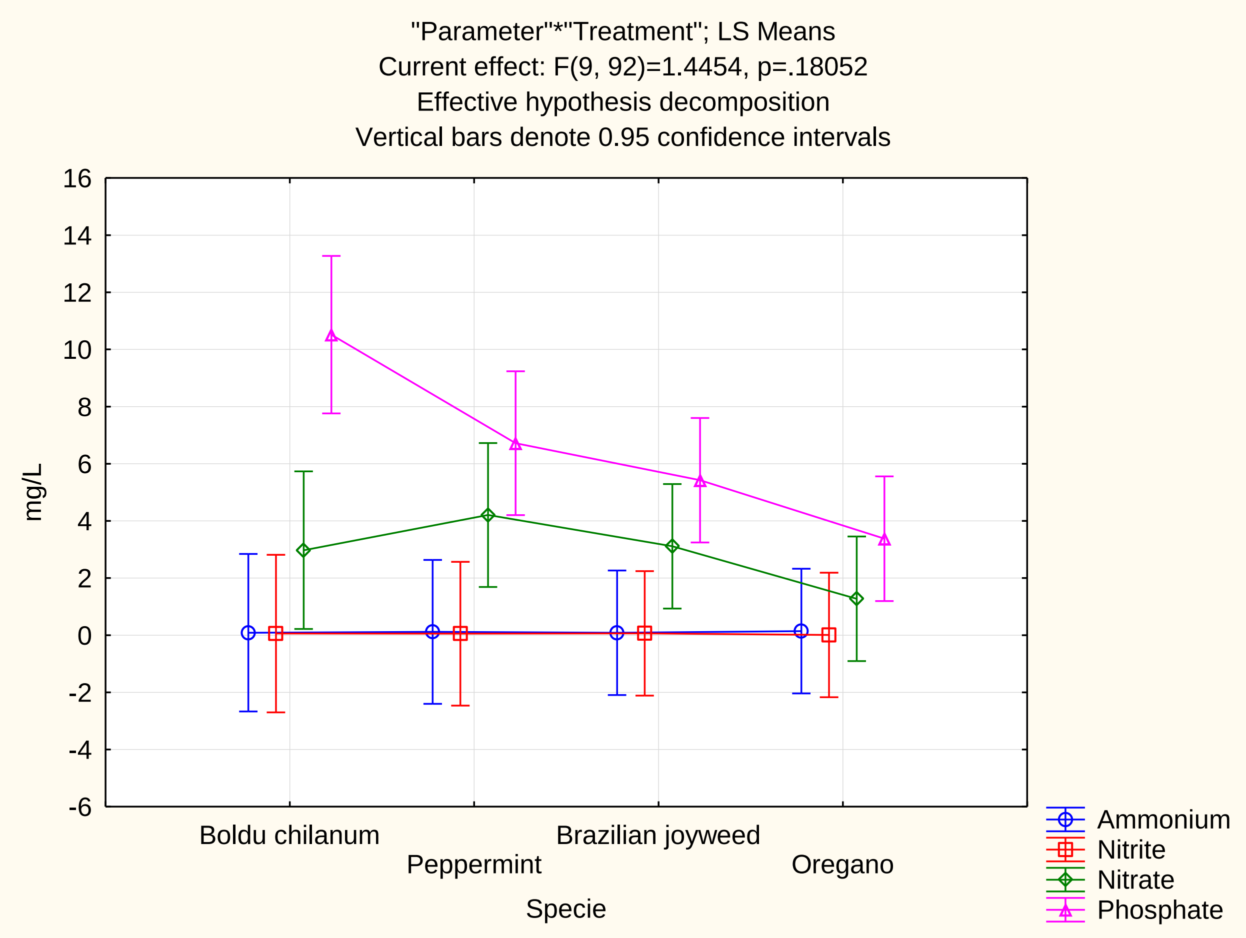

Figure 2. Averages of ions and cations water parameters by specie treatment.

3.2 Fish

As there were 21 fish.310L there were in total 336 goldfish individuals and biometrics, initial and final, were performed to measure fish growth. The results showed no statistical differences between treatments (Table 3 and Figure 3). During the experiment, 42 deaths of individuals were recorded, representing 12.5% of mortality.

Table 3. Fish parameters by treatment (plant specie) per phase.

Treatment/Parameter	(n)	Fish Weight (g)				Fish Total Length (cm)				Fish Standard Length (cm)			
		Initial	Final	t	p	Initial	Final	T	p	Initial	Final	t	p
Boldu chilanum	84	$10.59^{a}\pm10.929$	$19.676^{b}\pm13.844$	4.604	<0.0001	8.00^{a}	$10.074^{b}\pm2.342$	8.121	<0.0001	5.00^{a}	$6.927^{b}\pm1.531$	11.538	<0.0001
Peppermint	84	$9.16^{a}\pm3.53$	$16.855^{b}\pm6.244$	9.843	<0.0001	8.00^{a}	$10.018^{b}\pm1.423$	12.995	<0.0001	5.00^{a}	$6.661^{b}\pm0.892$	17.065	<0.0001
Brazilian joyweed	84	$8.048^{a}\pm4.915$	$18.543^{b}\pm7.196$	10.931	<0.0001	8.00^{a}	$10.096^{b}\pm1.449$	13.263	<0.0001	5.00^{a}	$6.857^{b}\pm0.972$	18.458	<0.0001
Oregano	84	$7.015^{a}\pm1.037$	$17.643^{b}\pm9.072$	10.657	<0.0001	8.00^{a}	$10.0^{b}\pm1.349$	13.585	<0.0001	5.00^{a}	$6.795^{b}\pm1.04$	15.82	<0.0001

Means followed by different letters between the lines in the columns of each parameter differ at 5% probability by the t-test.

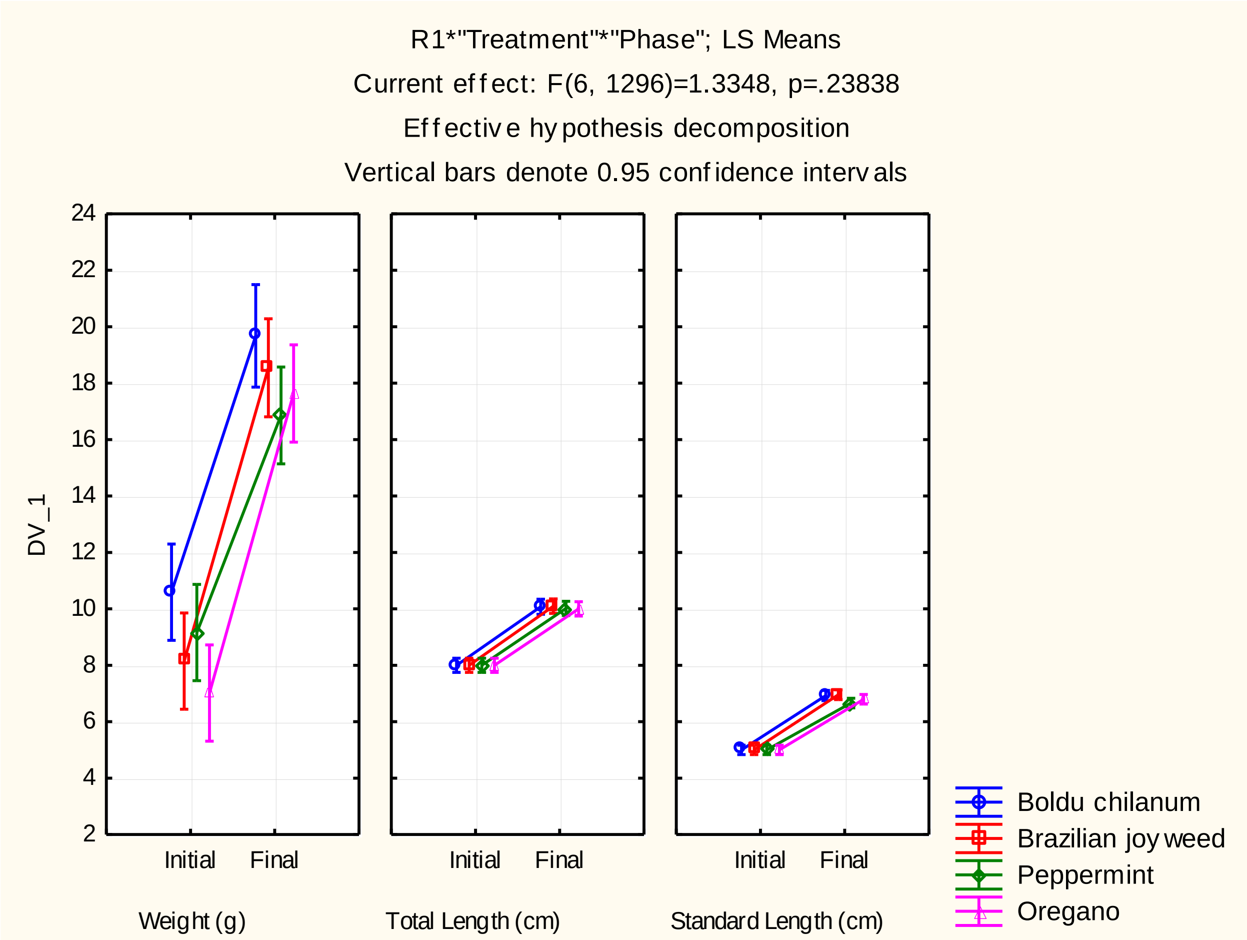

Figure 3. Averages of fish parameters by treatment per phase.

The initial biometric mean for the weight parameter (g) was 9.95^a ± 6.85 and final was 18.91^b ± 9.36, and for the initial total length it was 8.00^a and final of 10.17^b ± 1.72 and initial standard length (cm) of 5.00^a and final of 6.90^b ± 1.14 demonstrating differences between the initial and final averages according to t-test analyses.

3.3 Plants

Of the four species evaluated, three showed significant growth during the experiment, demonstrated by the statistical differences between the parameters evaluated (Table 4 and Figure 4), and the other specie, oregano, showed deficiency results for weight and height, also occurring mortality of individuals. In the number of leaves parameter, only oregano showed no statistical difference from the initial value.

Table 4. Results of the averages of biometric parameters by plant species.

Species/Parameter	(n)	Weight (g)				Heigh (cm)				Number of leaves			
		Initial	Final	t	p	Initial	Final	t	p	Initial	Final	t	p
Peumus boldus	16	11.56^{a}±1.32	1358.75^{b}±416.69	12.932	<0.0001	18.00^{a}±4.47	44.81^{b}±5.47	15.163	<0.0001	29.06^{a}±14.81	135.68^{b} ±14.89	20.301	<0.0001
Mentha x *piperita*	16	8.43^{a}±0.90	262.50^{b}±96.05	10.488	<0.0001	43.75^{a}±10.01	63.00^{b}±9.79	5.497	<0.0001	27.30^{a}±9.81	246.54^{b} ±52.75	22.042	<0.0001
Alternanthera brasiliana	16	11.56^{a}±1.23	105.14^{b}±85.38	4.395	0.0001	34.65^{a}±4.86	50.57^{ab}±22.84	2.724	0.011	13.06^{a} ± 2.40	42.17^{b} ± 23.60	41.773	<0.0001
Origanum vulgare	16	15.00^{a}±1.07	20.00^{a} ±14.93	1.356	0.1877	33.15^{a}±5.15	16.30^{b}±3.05	9.326	<0.0001	32.12^{a} ± 11.43	40.60^{a} ± 41.93	1.024	0.316

Means followed by different letters between the lines in the columns of each parameter differ at 5% probability by the t-test.

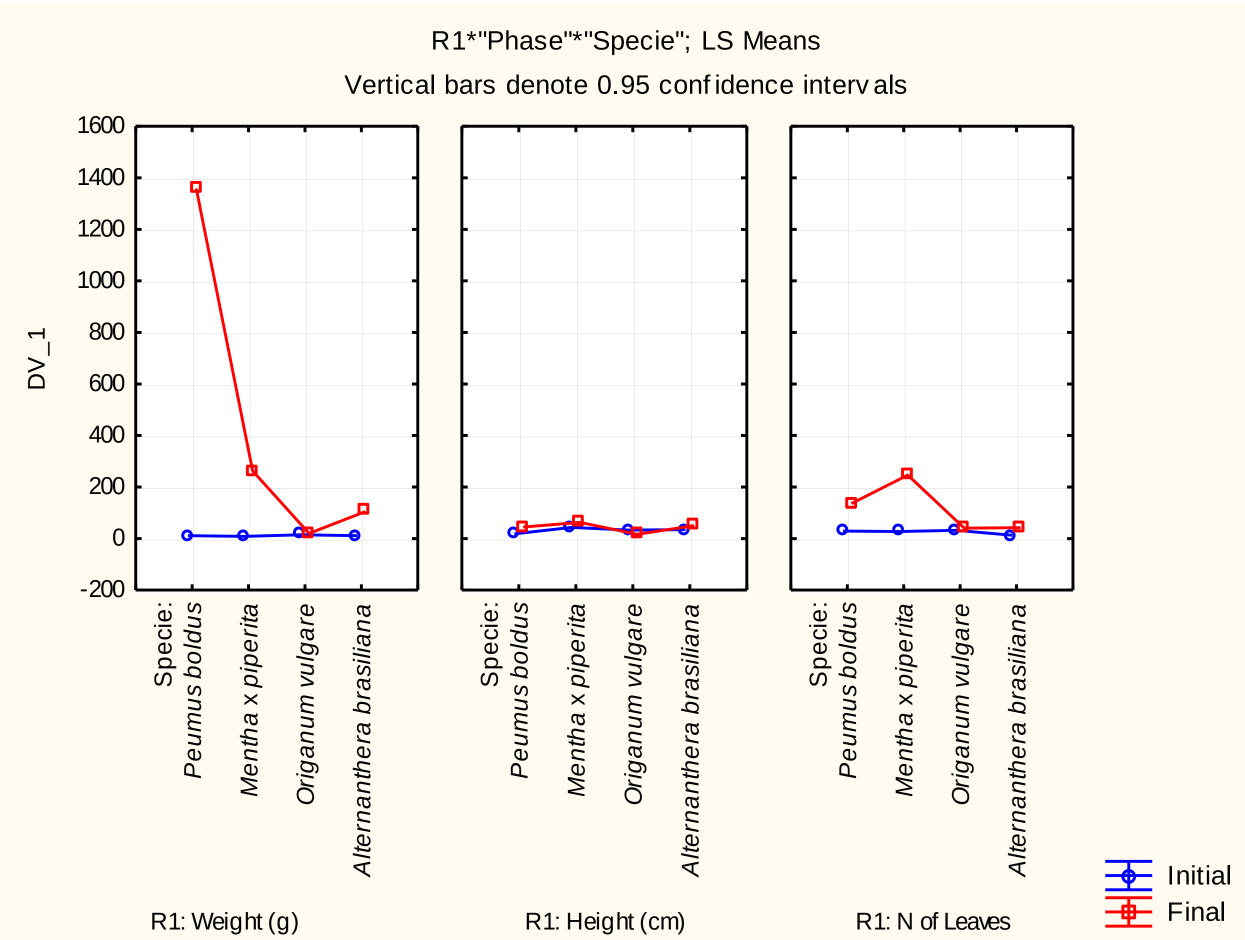

Figure 4. Averages of plant parameters by treatment per phase.

The results about the content, in percentage, of the total nitrogen of the leaves of the species boldu chilanum, Brazilian joyweed and peppermint were, respectively, 3.13^{a} ± 1.34, 4.31^{ab} ± 1.56 and 5.92^{b} ± 2.54 (F= 5.518; p=0.0091; df=32) by anova one-way and Tukey test analysis (Figure 5). The results of the experiment showed that the boldu chilanum and peppermint species obtained visibly productive performances in the system, while the Brazilian joyweed and oregano species, despite having resisted the period of cultivation in aquaponics, did not develop as expected, despite Brazilian joyweed increasing in height, weight and number of leaves.

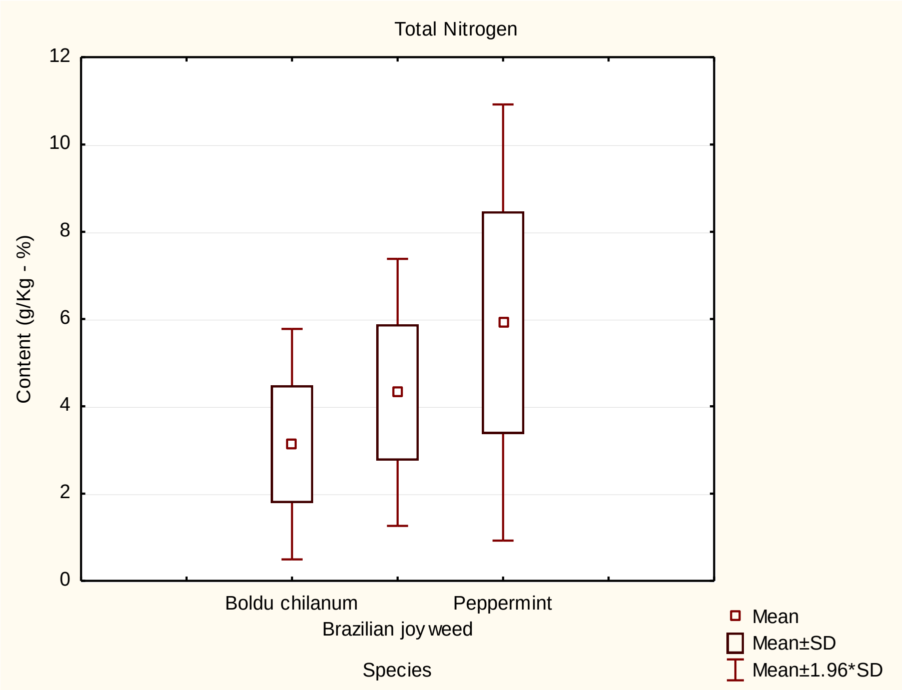

Figure 5. Graph of the content (g/kg - %) of Total Nitrogen in plant leaves.

A general linear models analysis was performed to relate the parameters of the elements of the aquaponic systems (Figure 6).

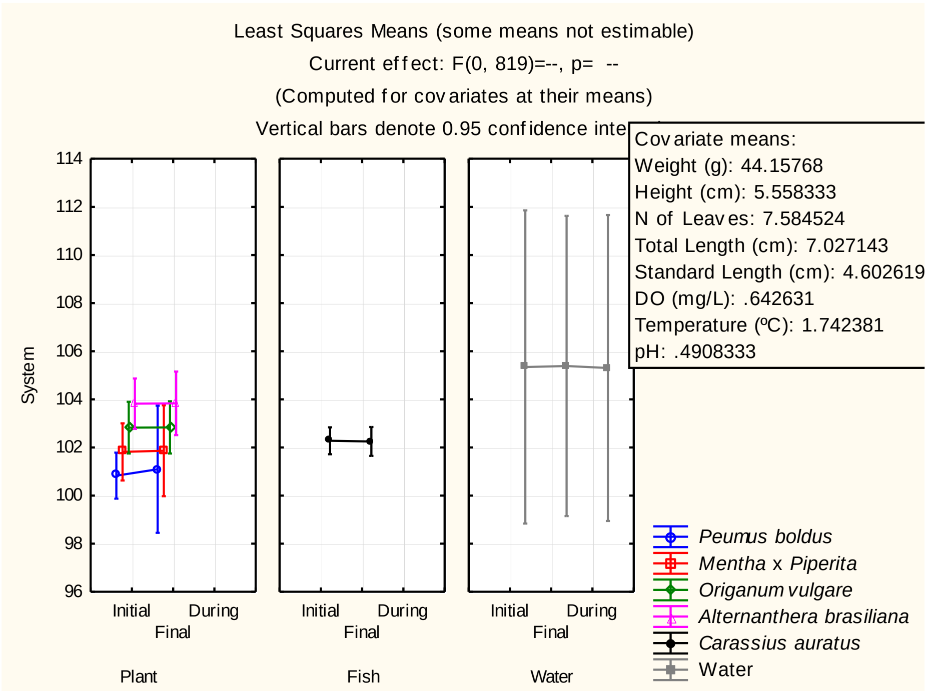

Figure 6. Graph of the aquaponic elements performances per phase.

4. Discussion

The physical-chemical parameters of water, temperature, dissolved oxygen concentration and pH, were within the optimal range for aquaponic systems as recommended by Somerville et al. (2014) and Carneiro et al.

(2015). Chemical analysis of ions and cations diluted in aquaponic solution did not show differences between treatments, however low levels of Nitrite are observed, since in aquaponics the nitrification process is favored, into Nitrate, the way plants absorb Nitrogen.

For the cultivation of goldfish, in order to maintaining the species' well-being, the ideal parameters according to the literature (Froese & Pauly, 2022) are in the range of 15 to 24°C, with an average of 19.3 ± 3 .2°C, thus, within the optimal range for the species. The fish showed statistically significant differences between the initial and final biometrics, and Froese & Pauly (2022) indicate that the goldfish reaches an average of up to 15 cm in length and that the larger size is more interesting for commercialization for aquarium hobbyists. The final length mean of the animals was 10.17 ± 1.72 cm, demonstrating the animal growth during the experiment.

The goldfish is commonly used as the aquatic organism in aquaponics systems all over the world (Rakocy et al. 2006; Yildiz et al. 2017). Patil et al. (2019) analyzed three stocking densities of this specie in association with basil in a growing bed aquaponic system, and in this 32 days experiment they observed the growth of the goldfish, which had its initial weight 3.32 ± 0.45 g and different final weights, but at all of them the weight gain (%) were higher than 160%. In our experiment, we found a weight gain of approximately 90%, with the fish having different life stages and staying longer in the system. It should be noted that the production of ornamental fish in aquaponics can differs from the purpose of other fish for human consumption, since the main interest is to reach the stage of maturation for reproduction and possibly for the population of ornamental ponds.

From the analysis of the results, it can be observed that the species boldu chilanum and peppermint obtained significant growth results in all parameters and in all implanted individuals, being totally viable their cultivation in tropical aquaponic bedding systems of substrate. The boldu chilanum plants had an average final height of 63.00 ± 9.79 cm in 91 days, while Vogel et al. (2011) found results of 74.5 and 67.6 cm of the same species grown in soil, but of plants already cultivated for four years and in longer sampling periods. The plants densities used in Vogel et al. (2011) experiment were 8 and 16 plants.m², and the authors did not find significant differences between these two treatments. In the experiment in question, the density used was 16 plants.m² and the results demonstrate a satisfactory development of boldu chilanum, implanted by cuttings, in aquaponics.

For peppermint, the average weight of total biomass per planter was 262.5±96.05, being 65.62g plant^{-1}, while Costa et al. (2012), who cultivated the same species in pots with prepared soil, shading with shades of different colors and lighting rate of 50%, obtained an average weight of 31g plant^{-1} in 120 days of experiment. Despite the seedlings in the experiment by Costa et al. (2012) were introduced smaller than that of the experiment in question, the comparison allows identifying that peppermint in aquaponics had excellent performance, demonstrating in the final weight gain its adaptation to the cultivation system.

Among the plant species analyzed in this study, peppermint is the only one that has studies of growth performance in aquaponic systems (Moyá et al. 2014; Roosta 2014; Shete et al. 2016; Pétrea et al. 2016; Nozzi et al. 2018 ; Ogah et al. 2020a; 2020b; Knaus et al. 2020). As there are different forms of plant cultivation in aquaponics, the same plant species can present different performance data from their cultivation method. While Pétrea et al. (2016) analyzes the performance in different cropping densities and in different cropping systems, Moyá et al. (2014), Shete et al. (2016) and Knaus et al. (2020) analyzed the specie in a cultivation system similar to the experiment carried out, media bed.

Kosakowska et al. (2019), in a study carried out to determine differences between the cultivation of oregano in open field and shaded environments cultivated organically, found higher productivity in dry mass of plants cultivated in excess than in open field (76.49 and 49.44g plant^{-1}, respectively). Murillo-Amador et al. (2013), in a similar experiment in Mexico, obtained results for dry mass productivity of 25.52 and 87.19 g plant^{-1}, for plants in open field and shade, respectively.

Studies that consider the production of organic oregano are scarce (Murillo-Amador et al. 2013) and that relate the species and aquaponics are null. The oregano individuals implanted and analyzed in the aquaponic systems in question did not obtain the expected growth, presenting some plants with lower weights than the initial ones and, on average, a decrease in the final height in relation to the initial. In addition to having presented mortality of six plants, representing 37.5% of the individuals of this species. The low performance of the species in the system may have been due to the non-adaptation of the species to the substrate (expanded clay) and/or the water regime in the system, since all systems received the same supply of feed for the fish and, consequently, same supply of nutrients to plants.

Brazilian joyweed, like all other species studied in this work, was introduced into the systems by cuttings and developed significantly, producing elongated branches and flowering during the experiment. Despite having presented the mortality of two plants, representing 12.5% of the individuals of this species, and some individuals having a final average height statistically similar to the initial, 50.57 cm, it proved to be in line with the maximum height of the species (30 to 50 cm), according to Lorenzi & Souza (1999).

Menegaes et al. (2014) investigated the performance of Brazilian joyweed at three different densities (1 plant/pot; 2 plants/pot and 3 plants/pot) and found better growth results in plants grown at higher densities in pots. The density used in the experiment in question was higher than in the aforementioned work, of four plants per 0.25m², that is, 16 plants^{-1}, and presented an average of final height values, 50.57cm, significantly higher than the 19.90cm from the experiment by Menegaes et al. (2014). The results demonstrate the potential of aquaponic production and the development of these plants using seedling propagation by cuttings.

The number of leaves in three of the four species studied boldu chilanum, peppermint and Brazilian joyweed, was considerably higher at the end of the experiment and, as this parameter is related to the plant parts used for the production of the drugs, they are the main products of plant production. According to Castro and Albiero (2016), 80% of the raw materials used by the pharmaceutical industry evaluated in their work are actually imported, leaving only 20% of the market for Brazilian producers. It is believed that investment in training small producers, in cultivation techniques, in agrarian technology and, mainly, in infrastructure could generate a higher quality product and, consequently, increase the sector's potential.

Another important aspect to be considered is that studies such as Bochner et al. (2012), Souza et al. (2012) and Castro and Albiero (2016) report on problems associated with the commercialization of medicinal plant species, mainly contamination and misclassifications. These problems were minimized in aquaponics, since from the selection of the correct species and their maintenance in a protected environment they allowed plant health.

5. Conclusion

The experiment demonstrated the potential of aquaponics in the production of medicinal plants, resulting in a significant increase in the number of leaves for the boldu chilanum, peppermint and Brazilian joyweed, corroborating the hypothesis of the possibility of using the technology in medicinal production, not showing positive results for the oregano. In addition, the animal species used also showed significant growth and the water quality parameters remained as recommended, both for aquaponic systems and for the well-being of the species used. As demonstrated in the experiment, boldu chilanum and peppermint species obtained representative growth and can be used for future experiments. New studies that address the issue of medicinal plants and different species of fish should be encouraged, in order to add final value to products from aquaponics.

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