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THE GROWTH AND DEVELOPMENT OF KALE AND ARUGULA IN AN AQUAPONIC SYSTEM

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Abstract

The objective of the current study was to determine the effect of two fish stocking densities on the growth performance, development, and antioxidant capacity of kale (Brassica oleracea L. var. acephala) and arugula (Eruca vesicaria ssp. sativa) in an aquaponic system with common carp (Cyprinus carpio). The aquaponics system consists of six rearing units for fish and twelve units for plants, purple light-led lamps for plants (36 W), biological and mechanical filters, and pumps for water recirculation. Two fish stocking densities were used: 3.5 kg×m^{-3} and 7 kg×m^{-3}, each replicated three times. For each treatment or fish stocking density, 15 kale seedlings (51 plants×m^{-2}) and 15 arugula seedlings (51 plants×m^{-2}) were planted. All treatments were done in triplicates. At the end of the trial, the fresh weight of the plants was measured, and the results showed that the stocking density of the common carp of 7 kg×m^{-3} resulted in higher production of kale and arugula by maintaining good water quality for the plant and fish.

***Key words**: aquaponic, carp, plant production.*

INTRODUCTION

Aquaponic systems are a sustainable and efficient method of producing both plant and fish products in a closed-loop system. This system integrates hydroponic plant production with aquaculture, where the fish waste provides the necessary nutrients for the plants to grow, while the plants purify the water for the fish (Sfetcu et al., 2008; Filep et al., 2016a; 2016b; Atique et al., 2023). Aquaponics systems do not waste energy, water, or nutrients (Rizal et al., 2018; Jansen & Keesman, 2022). Lately, these systems have become increasingly popular, mainly because of the numerous advantages compared to conventional agriculture. Aquaponics used less water than traditional farming methods because the water is recirculated within the closed-loop system.

Among the various crops that can be grown in aquaponic systems, kale, and arugula are two leafy green vegetables that are known for their high nutritional value and antioxidant activity. Kale (*Brassica oleracea var. acephala*) and arugula (*Eruca sativa*) are both members of the *Brassicaceae* family (Sikora & Bodziarczyk, 2012). Kale is rich in sources of dietary fiber, with a high content of vitamins A, K, and C, minerals, such as potassium (K), calcium (Ca), and magnesium (Mg), and significant amounts of carotene and folate (Walker & Weinstein, 1994). Arugula (*Eruca vesicaria* ssp. *sativa*) is a cruciferous vegetable commonly known as rocket salad which contains high levels of beneficial nitrates and polyphenols, and high levels of antioxidants, such as vitamins C, K, A, and iron (Amorim et al., 2007).

In the last years, there was a growing interest in using aquaponic systems to grow these leafy greens because of their fast growth and relatively lower operation costs and due to their increasing popularity and demand in the health food industry. Also, a big advantage of the production of these vegetables in the aquaponic systems is a veritable way of earning a stable income because yield is possible year-round. Good performance results have been obtained for growing kale and tilapia in an integrated aqua-vegeculture (IAVC) system, and deep-water culture (DWC) system (pilot-scale evaluation), at a stocking density of tilapia of 10 kg/m^3, while the density of kale seedlings was 25 plants/m^2 (Afolabi, 2020). In contrast, Barbosa et al., 2020, studied the growth of

arugula under two different system water volumes (500-L vegetable tank: 500-L fish tank, and 500-L vegetable tank:1000-L fish tank), and their results indicated poor growth performance mainly due to the extreme high sowing density of seedlings (40 seedlings of arugula per growing unit, approx. 0.160 kg/m^2).
In this context, this study aimed to evaluate the growth of kale and arugula vegetables in an aquaponic system, using as substrate Light Expanded Clay Aggregate (LECA), together with common carp (*Cyprinus carpio* L., 1758), stocked at two densities (SD1-3.5 kg×m^{-3}, respectively SD2-7 kg×m^{-3}). Also, the results of the study may contribute to developing integrated and sustainable food production using modern methods.

MATERIALS AND METHODS

Experimental design. The study was conducted for 41 days at the Aquaponics station of the Research Center for Modelling Recirculating Aquaculture Systems (MoRAS-www.moras.ugal.ro) of the Faculty of Food Science and Engineering, "Dunărea de Jos" University of Galați, Romania. The system consists of six rearing units for fish and twelve rearing units for plants, led lamps with purple light (36 W), biological and mechanical filtration, and pumps for water recirculation. The aquaponics system was previously described in our research (Crețu et al., 2022). For the experiment, a total number of 90 common carp were used (*Cyprinus carpio* L, 1758), with an average initial weight of 116.62 grams. Two fish stocking densities were created: SD1-3.5 kg×m^{-3}, and SD2-7 kg×m^{-3}, each replicated three times (Figure 1). The plant units were populated with 15 kale seedlings (*Brassica oleracea* var. *acephala*), respectively 15 arugula seedlings (*Eruca sativa*) in each rearing unit (51 plants/m^2). The substrate used for the growth of kale and arugula was represented by Light Expanded Clay Aggregate (LECA). The high surface area of the substrate provides more space for the growth of nitrifying bacteria. The plants were obtained from seeds in our laboratory and then transferred into the aquaponic system at 21 days.

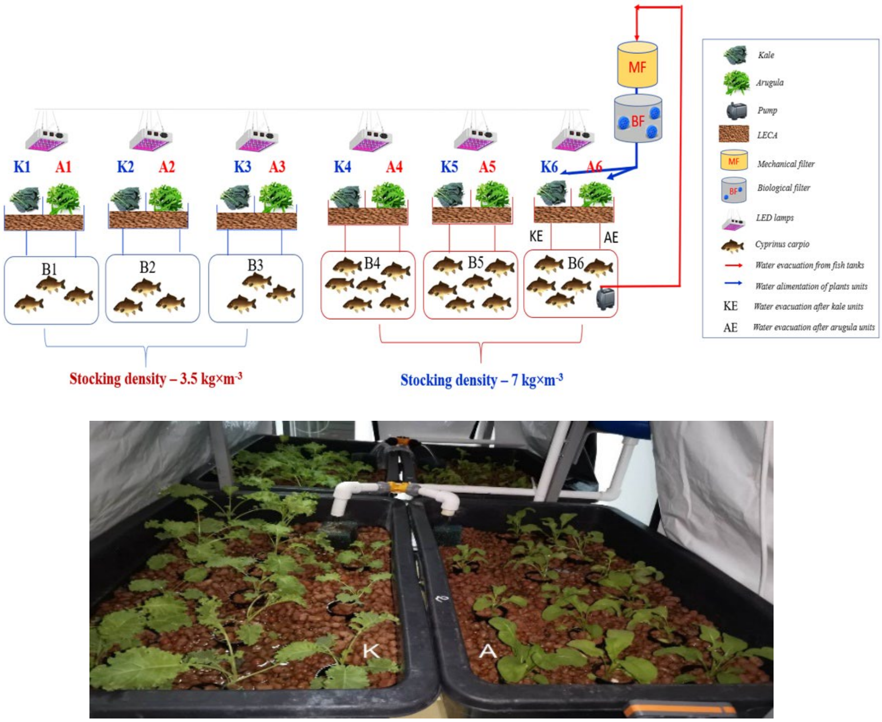

Figure 1. The scheme of the experimental design (K-kale, A-arugula)

During this trial, fish were fed two times a day at 08:00 a.m. and 4:00 p.m. at a rate of 2% of their body weight (BW), with a commercial diet (43% protein, 12% fat, 4% fiber, 6% ash).

Water quality. During the experimental period, the water quality parameters, such as dissolved oxygen, temperature, pH, and conductivity were measured daily with the help of a portable multiparameter Hanna HI98494 (Hanna Instruments, Cluj, Romania). The concentration of the nitrogen compounds ($N\text{-}NO_2^-$; $N\text{-}NO_3^-$, $N\text{-}NH_4^+$) was measured twice per week with the help of the Spectroquant Nova 400 photometer compatible with Merck kits (Merk Romania, Bucharest, Romania).

Fish and plant growth parameters. At the beginning of the experiment and the end, kale and thyme seedlings were measured for plant height (cm), plant weight (g), and roots height (cm). Fish growth parameters, including initial weight (g), final weight (g), weight gain (g), initial biomass (g), final biomass (g), feed conversion ratio (FCR), specific growth rate (SGR), and protein efficiency ratio (PER) were calculated:

- Weight Gain (WG) = Final Weight (Wt) (g) – Initial Weight (W0) (g);
- Food Conversion Ratio (FCR) = fish feed quantity (g)/WG (g) (g/g);
- Specific Growth Rate (SGR) = (ln Wt – ln W0)/t × 100 (% BW/day), where t - duration of the experiment;
- Protein efficiency ratio (PER) = Total weight gain (W)/amount of protein fed (g).

For the plant's evaluation, all plants were weight individually at day 0 (when plants were transferred into the aquaponic system) and at day 41 (when plants were removed from the aquaponic system).

Data analysis. All collected data were analyzed with the SPSS 21.0 (SPSS Company Inc., Chicago, IL. USA) statistical software package and Microsoft Excel. Statistically significant differences were reported at $p<0.05$.

RESULTS AND DISCUSSIONS

Water quality in the aquaponic system. In an aquaponic system, the physicochemical parameters played a significant role in obtaining a successful production. The water quality variables were maintained at adequate levels for the rearing of carp while providing the necessary nutrients for plant growth (Table 1). The temperature was in the optimum range for the growth of carp (Muralitharan & Dhanushsri, 2022), without any significant differences ($p>0.05$) between the growing units of carp and plants. Regarding the growth of plants, kale is a cool-season vegetable that grows best in temperatures between 15-18°C but can tolerate temperatures as 27°C degrees for short periods (Afolabi, 2020), while for optimal growth of arugula, the temperatures should be about 25°C (Furlani et al., 1999). The dissolved oxygen and pH values registered no significant ($p>0.05$) different values between the growing units of carp and plants. Regarding the values of the nitrogen compounds, significantly lower values ($p<0.05$) were recorded between the rearing units of carp and after the water evacuation from the growing units of Kale and arugula. The lowest values were recorded after the evacuation of water from the plant units.

Table 1. The physicochemical parameters of water during the experimental trial

Parameter	Fish tanks		Plant tanks				
	SD1	SD2	AAU	KE		AE	
				SD1	SD2	SD1	SD2
Temperature (°C)	21.2±0.10	21.4±0.09	21.30±0.10	21.4±0.09	21.09±0.11	21.4±0.08	21.8±0.10
Oxygen (mg×L^{-1})	7.21±0.76	7.62±0.64	7.18±0.10	7.16±0.10	7.26±0.11	7.41±0.12	7.36±0.09
pH (pH units)	7.68±0.11	7.61±0.12	7.65±0.19	7.39±0.14	7.46±0.16	7.36±0.12	7.26±0.11
$N\text{-}NO_2^-$ (mg×L^{-1})	0.04±0.013	0.05±0.011	0.03±0.013	0.01±0.011	0.02±0.011	0.01±0.016	0.03±0.013
$N\text{-}NO_3^-$ (mg×L^{-1})	27.80±4.52	32.4±8.12	18.63±3.12	12.10±4.52	16.09±6.53	11.56±6.23	9.24±9.45
$N\text{-}NH_4^+$ (mg×L^{-1})	0.47±0.17	0.61±0.78	0.46±0.15	0.25±0.11	0.33±0.19	0.29±0.26	0.44±0.16
Conductivity (μS/cm)	1923±65.50	1931±89.62	1896±89.16	1889±75.16	1894±76.14	1923±85.13	1965±85.45

Note: AAU- alimentation of the aquaponic units (after the evacuation of mechanical and biological filtration); KE- water evacuation after growing units of Kale; AE- water evacuation after growing units of arugula; Fish tanks- SD1 - the values are presented as the mean±SD of the B1, B2, and B3 1tanks; SD2- the values are presented as the mean values of the B4, B5, and B6 tanks; Plant tanks- KE- SD1 - the values are presented as the mean±SD of the K1, K2, and K3 tanks; KE- SD2 - the values are presented as the mean±SD of the K4, K5, and K6 tanks; AE- SD1 - the values are presented as the mean±SD of the A1, A2, and A3 tanks; AE- SD2 - the values are presented as the mean±SD of the A4, A5, and A6 tanks;

Conductivity can be an effective way to estimate the fertilizer content via salts. In our experiment, electrical conductivity registered slightly higher values, with significant differences ($p<0.05$) between the fish-rearing units and plant units, but are in line with those reported by Al-Hafedh et al., 2008. Fish waste contains high levels of ammonia, which is toxic to fish but can be converted into nitrite and then nitrate by beneficial bacteria from the aquaponic system. Nitrate is a form of nitrogen that plants can readily absorb, and it serves as the primary source of nutrients for plants. In our experiment, it was observed that plants absorb nitrogen compounds. Choosing adequate plant density can help to reduce nitrogen levels in the water. Also, the good functionality of mechanical filtration and biological filtration is essential to maintain good water quality and reduce nitrogen compounds.

Plants Growth in Aquaponic System. Figures 2-5 and Table 2 present the plant's productivity.

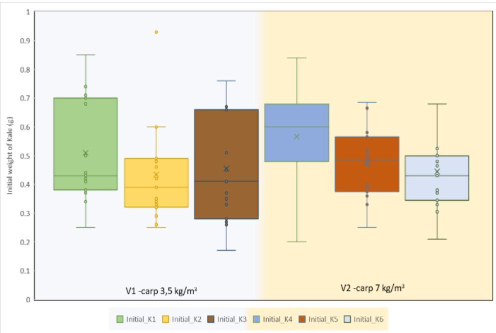

Figure 2. The distribution of the initial weight of kale

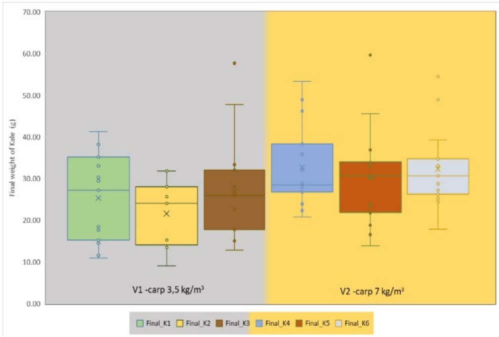

Figure 3. The distribution of the final weight of kale

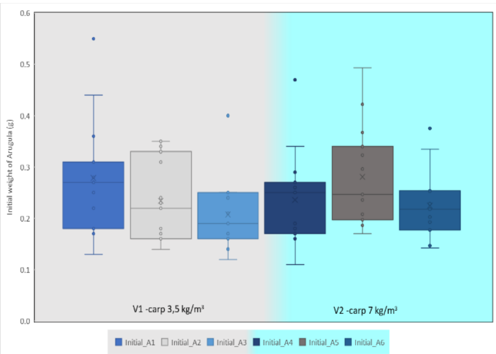

Figure 4. The distribution of the initial weight of arugula

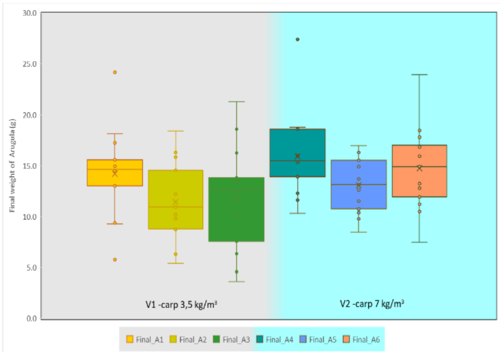

Figure 5. The distribution of the final weight of arugula

Table 2. Plant growth data from the aquaponic system

Parameter	Experimental moment	Kale		Arugula	
		SD1	SD2	SD1	SD2
Individual weight (g)	Initial	0.47±0.15	0.49±0.13	0.24±0.06	0.25±0.06
	Final	24.56±8.51	31.76±5.57	12.50±3.87	14.60±2.71
Plant biomass (g)	Initial	6.99±0.58	7.41±0.95	3.6±0.54	3.71±0.44
	Final	368.41±40.37	476.37±18.32	187.57±22.36	219.06±21.41
Root length (cm/plant)	Initial	2.16±0.05	3.08±0.09	2.04±0.03	2.15±0.04
	Final	13.5±3.69	19.16±3.71	15.45±3.6	18.53±2.66
The foliar surface of the leaf (cm^2/plant)	Initial	6.51±2.02	8.27±2.31	3.21±0.99	3.49±1.01
	Final	112.06±25.96	118.54±19.07	84.28±23.30	95.35±19.78

Note: *Kale*: SD1 - the values are presented as the mean±SD of the K1, K2, and K3 tanks; SD2 - the values are presented as the mean±SD of the K4, K5, and K6 tanks; *Arugula*: SD1 - the values are presented as the mean±SD of the A1, A2, and A3 tanks; SD2 - the values are presented as the mean±SD of the A4, A5, and A6 tanks.

The mean initial weight of kale was 0.47±0.15 g in SD1, respectively 0.49±0.13 g in SD2 ($p>0.05$), while arugula has lower individual weight: 0.24±0.06 g in SD1, respectively 0.25±0.06 g in SD2 ($p>0.05$). The mean final weight of kale was significantly higher ($p<0.05$) in the SD2 (31.76±5.57 g) in comparison with kale from the SD1 (24.56±8.51 g). Also, for arugula, a higher individual weight was obtained in the SD2 variant (14.6±2.71), but no statistical differences ($p>0.05$) were recorded (SD1-12.5±3.87 g). Lennard and Ward (2019), reported a final weight of arugula (after a growing period of 42 days in an NFT aquaponic system) of 10.7 g. Barbosa et al. (2020), reported for arugula a final weight of 14 g (plant density - 50 seedlings/m^2). In terms of the final plant roots, the statistical analysis revealed that the kale and arugula roots are significantly lower ($p<0.05$) in SD1 compared to those from SD2. The foliar surface of plants can be an indicator of the plant's ability to capture light and photosynthesize and offers information regarding the final yield (Pelil et al., 2018). The foliar surface of the leaves can vary depending on several factors, such as the density of the planting, and the growth conditions (Pérez et al., 2022). For kale and arugula, the result showed that the final foliar surface of leaves was higher in SD2, but there were no statistical differences ($p>0.05$) in comparison with SD1 (Figures 6-9). Kale has a final foliar surface of 118.54±19.07 cm^2/plant in SD2, respectively 112.06±25.96 cm^2/plant in SD1.

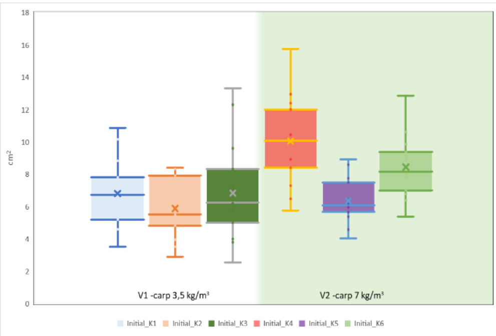

Figure 6. Leaf area of kale at the initial moment

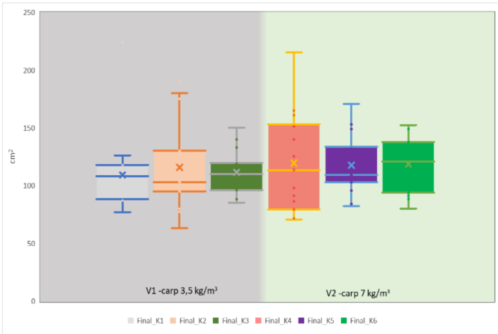

Figure 7. Leaf area of kale at the final moment

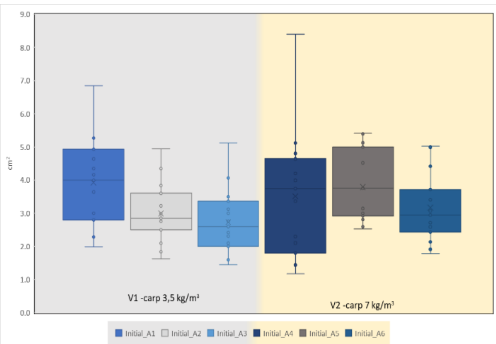

Figure 8. Leaf area of arugula at the initial moment

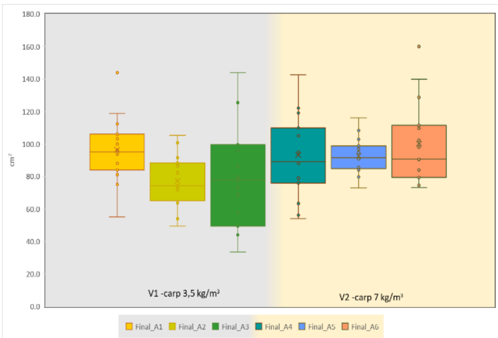

Figure 9. Leaf area of arugula at the final moment

Fish growth performance. Fish growth performance is presented in Table 2, and Figure 10. The initial mean weight of fish was 116.60±11.26 g at the SD1, respectively 116.63±14.52 g at the SD2. The results showed that aquaponics technology combined with different stocking densities of carp showed significant differences in fish growth ($p<0.05$). At the end of the experiment, the final fish weight was significantly higher ($p<0.05$) in fish stocked at a density of 3.5 kg×m^{-3}. The fish stocking density increased from the initial value of 3.50 kg×m^{-3} to 5.72 kg×m^{-3}, respectively from 7 kg×m^{-3} to 9.18 kg×m^{-3}.

Also, regarding the main technological indicators (SGR, FCR, and PER) better values were obtained in carp stocked at lower density (3.5 kg×m^{-3}).

Table 2. Fish growth performance at the end of the experiment

Growth parameters	3.5 kg×m^{-3}	7 kg×m^{-3}
Initial biomass (g)	1749±15.42	3499±17.29
Initial biomass (kg/m^3)	3.50±0.41	7.00±0.54
The initial number of fish	15	30
Mean initial weight (g)	116.60±11.26	116.63±14.52
Final biomass (g)	2860±28.16	4700±34.26
The final number of fish	15	30
Mean final weight (g)	190.67±16.45	156.67±19.24
Biomass weight gain (g)	1111±15.65	1201±21.63
Final stocking density (kg/m^3)	5.72±0.26	9.18±0.63

Note: 3.5 kg×m^{-3} - the values are presented as the mean±SD of the B1, B2 and B3 tanks; 7 kg×m^{-3}- the values are presented as the mean values of the B4, B5 and B6 tanks.

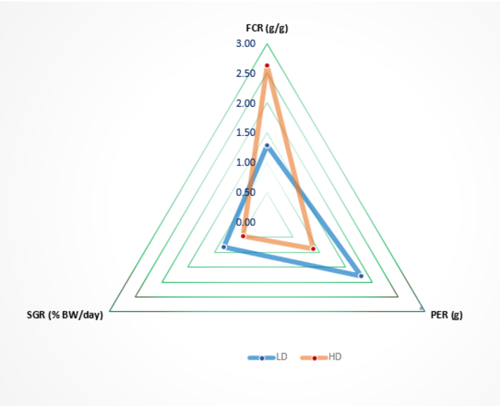

Figure 10. Specific growth rate (SGR), feed conversion ratio (FCR) and protein efficiency ratio (PER) for common carp held in different stocking densities

The results of our study indicate that the fish were able to develop properly due to the adequate densities of fish and vegetables, which, overall ensured good water quality. In aquaponics, choosing the optimum stocking density is an important factor to optimize both fish and vegetable production without compromising the water quality. Overstocking of fish can lead to poor water quality (Di Marco et al., 2008) while the plants may not be able to consume all of the nutrients produced by the fish waste. On the other hand, if the fish stocking density is too low, there may not be enough waste to support optimal plant growth (Diver, 2006).

CONCLUSIONS

In the present study, the co-cultivation of common carp and two leafy vegetables (kale and arugula) was performed in an aquaponic system, for 41 days. Based on our results, it can be concluded that the larger biomass of kale and arugula obtained in the aquaponic system, indicates a big potential of these vegetables for higher production, in combination with common carp.

In our experiment, the studied plants act as a biological filter, suggesting that an aquaponics system is a potential method to grow vegetable biomass, being also a very eco-friendly aquaculture system.

Overall, the growth of common carp at a stocking density of 7 kg×m^{-3} in combination with kale and arugula (plant density of 51 plants×m^{-2}) showed better results in terms of plant growth, but the results were unsatisfactory in terms of fish growth.

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