ISSN 2316-6886
WRIM

Water Resources and Irrigation Management
v.13, n.1-3, p.60-71, 2024
DOI: 10.19149/wrim.v13i1-3.4795

Cruz das Almas, BA, Brazil – https://www3.ufrb.edu.br/seer/index.php/wrim/index

---

ORIGINAL PAPER

Rocket microgreen cultivation under seeding densities and nutrient solution concentrations

Mairton Gomes da Silva[1,2]*; Luan Silva Sacramento[2]; Glaucia Silva de Jesus Pereira[2]; Maria Carolina Borges de Oliveira Ribeiro[2]; Izaiana dos Santos Barros[2] & Hans Raj Gheyi[1,3]

[1]Post Graduate Program in Agricultural Engineering, Federal University of Recôncavo da Bahia, Cruz das Almas, Brazil
[2]Center of Agricultural, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia, Cruz das Almas, Bahia, Brazil
[3]Post Graduate Program in Agricultural Engineering, Federal University of Campina Grande, Campina Grande, Paraíba, Brazil

Abstract: The consumption of leafy vegetables, such as microgreens, has increased. However, its cultivation still lacks management information. This study evaluated rocket microgreen cultivation under seeding densities and nutrient solution concentrations. The experiment was conducted in a randomized block design in split-plot, which consisted of five irrigation treatments in the main plots: supply water with electrical conductivity – EC of 0.3 dS m^{-1}; nutrient solutions with EC of 0.6 and 1.2 dS m^{-1} at 50 and 100% concentrations of "Flex mudas 1" and "Flex mudas 2" Plantpar® compounds; nutrient solutions with EC of 0.5 and 1.0 dS m^{-1} at 25 and 50% concentrations, as recommended by Furlani. Densities of five or ten seeds per 2×2×2 cm cell were used as a subplot. Microgreens were cultivated for 14 days, analyzing seedling height, seedling fresh matter (SFM), seedling dry matter (SDM), water use efficiency of SFM and SDM, seedling water content, seed mass to produce 1 kg of SFM, and sodium, potassium, and chloride contents in seedlings. The highest production and potassium accumulation in rocket microgreens occurred under higher solution EC levels (1.0 and 1.2 dS m^{-1}) produced with different formulations. Microgreens showed higher yield with a density of 10 seeds $cell^{-1}$.

Keywords: Functional food, soilless cultivation, natural resources, water use efficiency, yield.

Introduction

Technological advances increase the offer of industrialized food products. Hence, the risk of diseases associated with diet habits has also increased. In this sense, the diet habits of populations are frequently changing toward consuming more natural products, such as fresh vegetables.

The increasing population demand for agricultural foods has damaged natural resources, such as water and arable soils, and climate changes further aggravate this

---

* Corresponding author: E-mail: mairtong@hotmail.com

Editors: Petterson Costa Conceição Silva & Selma Cristina da Silva
Received in: March 20, 2024
Accepted in: April 17, 2024

scenario. Therefore, traditional cultivation systems require changes, such as migrating to production systems compatible with water and soil availability (Gonnella and Renna, 2021; Fussy and Papenbrock, 2022; Mir et al., 2022; Silva et al., 2024).

Thus, hydroponics is a cultivation technique with potential application to small locations with little water availability (Silva et al., 2023; Silva et al., 2024). It consists of soilless cultivation using nutrient solutions, as plants may grow using different techniques directly in nutrient solutions or substrates as growth media.

Soilless cultivation may be performed in different spaces (with natural and/or artificial lighting) from urban centers and/or surroundings, such as building interiors or roofs, office rooms, industrial factories, containers, warehouses, and underground locations (Sparks and Stwalley III, 2018; Velazquez-Gonzalez et al., 2022). In this case, commercial facilities near end consumers provide benefits such as product cost reduction (production site closer to consumers, consequently generating lower transportation and storage costs) and increase product shelf-life expectation, considering the high product waste during transportation due to the perishability of fresh produce (Parkes et al., 2022).

Seed-producing companies often launch new vegetable materials that are increasingly precocious and have high nutrient contents. Thus, microgreens are an emerging class of functional fresh food with a high potential to improve the human diet by filling nutritional deficiencies due to their phytochemical content (Kyriacou et al., 2019; Petropoulos et al., 2021; Partap et al., 2023; Tilahun et al., 2023; Vrkić et al., 2024). They are fresh vegetables consumed young (with fully developed cotyledon leaves), usually harvested up to two weeks after sowing (Xiao et al., 2015; Corrado et al., 2022; Bhaswant et al., 2023), increasing the number of production cycles throughout the year compared to adult plant cultivation (Thepsilvisut et al., 2023).

Microgreens are sown with high density, varying according to species (Thuong and Gia, 2020; Li et al., 2021ab; Moraru et al., 2022; Di Gioia et al., 2023). The present study used rocket (*Eruca sativa* Mill.), sown at densities of 55 g m^{-2} (Murphy and Pill, 2010), 45 g m^{-2} (Bulgari et al., 2017), 100 g m^{-2} (Wieth et al., 2021), 202 g m^{-2} (Bulgari et al., 2021), and 93 g m^{-2} (Kathi et al., 2022). Other studies did not inform the seeding densities (Kong et al., 2019a; Ying et al., 2020; Kong et al., 2023).

Also, microgreens have been irrigated with nutrient solutions at different concentrations. Therefore, electrical conductivity (EC) levels vary. Wieth et al. (2021) cultivated rocket microgreens in different substrates and solution EC levels (ECsol of 1.2 and 2.0 dS m^{-1}). The study presented varied data. For instance, vermiculite and organic Carolina Soil® (peat + vermiculite) substrates yielded 3.5-fold more fresh biomass under ECsol of 2.0 dS m^{-1}, while ECsol of 1.2 dS m^{-1} were 2.7- and 1.8-fold higher, respectively, irrigated with only rainwater (ECw ~ 0 dS m^{-1}). The phenolic foam substrate produced 2.4-fold more microgreens under ECsol of 1.2 and 2.0 dS m^{-1} than under ECw.

Therefore, this study evaluated rocket microgreen cultivation under seeding densities and nutrient solution formulations/concentrations.

Materials and Methods

Study site, experimental design, and growth conditions

This study conducted one experiment with rocket microgreens grown in hydroponic nutrient solutions in a greenhouse (east-west orientation and uncontrolled conditions with natural sunlight: protected by black screens with 50% shading, and the roof was covered with 150-µm-thick polyethylene transparent film), in August 2023. The facilities are part of the experimental area of the Post Graduate Program in Agricultural Engineering of the Federal University of Recôncavo da Bahia (UFRB), Cruz das

Almas, Bahia (12° 40’ 19” S, 39° 06’ 23” W, at an elevation of 220 m above sea level), Brazil.

The experiment was carried out in a randomized block design with four repetitions. An arrangement in split-plot was used, which consisted of five irrigation treatments in the main plots (each experimental unit comprised a Styrofoam tray with 18×24 cm): T1 – supply water with electrical conductivity (EC) of 0.3 dS m^{-1}; T2 and T3 – nutrient solutions with EC of 0.6 and 1.2 dS m^{-1} at 50 and 100% concentrations of a commercial fertilize for seedlings “Flex mudas 1” and “Flex mudas 2” (Plantpar® Indústria e Comércio de Fertilizantes Ltda., Umuarama, PR, Brazil); T4 and T5 – nutrient solutions with EC of 0.5 and 1.0 dS m^{-1} at 25 and 50% concentrations, as Furlani et al. (1999) recommended for leafy vegetables. Densities of five or ten seeds per cell 2×2×2 cm (corresponding to 0.01 and 0.02 g cell^{-1} or 25 and 50 g m^{-2}, respectively) were used as a subplot to the same tray using phenolic foam as a growth medium. Forty cells per tray were used (20 for each density, corresponding to a total area of 80 cm^2).

Rocket sowing and nutrient solutions preparation and management

Surya rocket (Isla® Sementes Ltda., Porto Alegre, RS, Brazil) was sown on August 12, 2023. After seeding in phenolic foam, the seeds were covered by a layer of coconut substrate. Until germination on first three days, the cells in the trays underwent manual irrigation with deionized water. Then, irrigation followed the tested treatments (supply water or nutrient solutions with different EC levels) until harvesting.

Supply water showed the following results, in mg L^{-1}: $K^+ = 2.87$, $Na^+ = 29.67$, $Ca^{2+} = 16.00$; $Mg^{2+} = 12.40$, and $Cl^- = 66.38$. The nutrient solutions were prepared in deionized water. The following nutrient amounts were used: 510 mg L^{-1} “Flex mudas 1” (in mg L^{-1}, 45.90 nitrogen, 35.70 phosphorus, 188.70 potassium, 12.24 sulfur, 6.63 magnesium, 0.714 iron, 0.255 boron, 0.255 manganese, 0.153 copper, 0.102 zinc, and 0.051 molybdenum) and 510 mg L^{-1} “Flex mudas 2” (in mg L^{-1}, 56.10 nitrogen, 81.60 calcium, and 8.16 magnesium) at 100% concentration, for T3; for T2, half-strength nutrient solution (at 50% concentration) was used. The standard nutrient solution recommended by Furlani et al. (1999) as a reference for leafy vegetables was used for T4 and T5 at 25 and 50% concentrations, respectively. For T5, the following nutrient amounts, in mg L^{-1}, were used: 375 calcium nitrate, 250 potassium nitrate, 75 monoammonium phosphate, and 200 magnesium sulfate. Consequently, T4 was half of these amounts. They were obtained separately from the Dripsol® fertilizer (SQM Vitas Brazil, Candeias, BA, Brazil). Micronutrients were provided using 6.25 or 12.50 mg L^{-1} Micromix® (T4 and T5, respectively) and 4 or 8 mg L^{-1} GeoQuel® 13% Fe-EDTA (T4 and T5, respectively) (Rigrantec Tecnologias para Sementes e Plantas Ltda., Porto Alegre, RS, Brazil).

Evaluated traits

Fifteen days after sowing, all seedlings were harvested from each tray (cutting around 2 mm above the phenolic foam level). The study determined seedling height (SH, in cm) and seedling fresh matter of 20 cells per density in the cultivation tray (SFM, in g 80 cm^{-2}). Immediately after weighing the fresh seedlings, the material was placed in paper bags and dried in a Q314M forced-air oven (Quimis®, Diadema, SP, Brazil) at 65°C until reaching constant weight to quantify the seedlings dry matter (SDM, in g 80 cm^{-2}). Next, SFM was calculated (g 4 cm^{-2}) for 2×2×2 cm of a phenolic foam cell. The production from an area of 80 cm^2 was the basis for extrapolating microgreen yield (g m^{-2}), i.e., 1 m^2.

Water content (WC) was calculated based on difference between the fresh (FM) and dry (DM) matter of microgreens seedlings: WC (%) = [(FM − DM)/FM] × 100.

Seed mass (in g) was also calculated to produce 1 kg of SFM of microgreens. Water productivity was determined and expressed as water consumption (water or water plus nutrients) to produce 1 kg of SFM of microgreens.

Sodium (Na^+), potassium (K^+), and chloride (Cl^-) contents in the plant material were determined. For this, the dry plant material was crushed and 0.1 g was added to tube filled with 10 mL of deionized water. The tubes were heated to 100°C in a water bath for 1 h, with agitations every 15 min. The supernatants were filtered in a quantitative filter paper for further analysis. Na^+ and K^+ contents were determined in a flame photometer model BFC – 300 (Benfer, São Paulo, SP, Brazil). The Cl^- content was determined in a UV VIS spectrophotometer model SP-2000UV (Bel Equipamentos Analíticos Ltda., Piracicaba, SP, Brazil), using a solution of mercury thiocyanate in absolute methanol plus iron nitrate at 20.2%.

Statistical analysis

The data were subjected to the normality test (Shapiro-Wilk) and subsequently subjected to analysis of variance by F-test ($p \leq 0.05$). The means obtained as function of the electrical conductivity levels (water and nutrient solutions) in the main plots were separated using the Scott-Knott test ($p \leq 0.05$). The means obtained according to seed density were compared using Tukey's test ($p \leq 0.05$). In addition, the magnitude of the relationships among the traits analyzed was performed by Pearson's linear correlation.

Results and Discussion

The interaction between electrical conductivity levels (water or nutrient solutions) and seeding densities was not significant ($p > 0.05$) in any evaluated trait (seedling height – SH, seedling fresh matter – SFM, seedling dry matter – SDM, seedling water content – SWC, water use efficiency of SFM and SDM – WUE_{SFM} and WUE_{SDM}, and seed mass – SM) of rocket microgreens (Table 1). As for isolated effects, EC levels significantly affected ($p <$ 0.01) all traits, and the seeding density function behaved equally, except for SH and SWC.

As expected, the lowest means occurred in irrigation with only supply water (without nutrient addition), under EC of 0.3 dS m^{-1} (Table 1), as seen in Figure 1. SFM responses (per cell, per 20 cells, and per m^2) of rocket microgreens were similar regarding EC levels, with the highest means recorded under solution EC (ECsol) of 1.2 dS m^{-1} (produced with the commercial formulation "Flex mudas 1" and "Flex mudas 2" Plantpar®). The means under these cultivation conditions (0.54 g $cell^{-1}$, 10.88 g 20 $cells^{-1}$, and 1360.31 g m^{-2}) were approximately 2.3-fold higher than those under irrigation with only water (ECw of 0.3 dS m^{-1}).

The second-best treatment concerning SFM was with ECsol of 1.0 dS m^{-1}, applying the formulation by Furlani et al. (1999) at a 50% concentration (Table 1). Therefore, the best rocket responses occurred under the highest ECsol levels with different nutrient sources. The ECsol of 1.0 dS m^{-1} yielded means (0.47 g $cell^{-1}$, 9.35 g 20 $cells^{-1}$, and 1169.06 g m^{-2}) around 2.0-fold higher than those under ECw. The treatment with ECsol of 1.0 dS m^{-1} provided approximately 14% lower means than ECsol of 1.2 dS m^{-1}. Regardless of solution compositions, the means were statistically equivalent under the lowest ECsol levels (0.5 and 0.6 dS m^{-1}). In treatment with only water the SFM accumulation varied between 61 and 63% in comparison to lowest ECsol levels.

Table 1: Results of analysis of variance and means for seedlings height (SH), seedlings fresh matter (SFM), seedlings dry matter (SDM), seedlings water content (SWC), water use efficiency based on SFM (WUE_{SFM}) and SDM (WUE_{SDM}), and seed mass (SM) to produce 1 kg of SFM of rocket microgreens grown at two seed density (SD) and different levels of electrical conductivity (EC) of water or nutrient solutions

SV	SH cm	SFM g cell^{-1}	SFM g 20 cells^{-1}	SFM g m^{-2}	SDM g cell^{-1}	SDM g 20 cells^{-1}	SDM g m^{-2}	SWC %	WUE_{SFM} L kg^{-1}	WUE_{SDM} L kg^{-1}	SM g
EC											
0.3 dS m^{-1}	3.91 ± 0.18c	0.23 ± 0.02d	4.64 ± 0.35d	580.00 ± 44.09d	0.025 ± 0.001c	0.488 ± 0.012c	60.79 ± 1.57c	89.50 ± 0.61c	74.13 ± 8.34a	705.55 ± 40.06a	63.26 ± 4.85a
0.6 dS m^{-1} – Plantpar	5.23 ± 0.38b	0.35 ± 0.05c	7.02 ± 0.90c	877.81 ± 112.81c	0.029 ± 0.003c	0.558 ± 0.060b	69.51 ± 7.49b	91.99 ± 0.41b	54.39 ± 9.43b	673.66 ± 100.28a	43.09 ± 6.28b
1.2 dS m^{-1} – Plantpar	6.93 ± 0.49a	0.54 ± 0.04a	10.88 ± 0.88a	1360.31 ± 110.53a	0.039 ± 0.003a	0.790 ± 0.067a	98.68 ± 8.43a	92.72 ± 0.28a	36.94 ± 3.10c	508.81 ± 62.94b	27.80 ± 2.32c
0.5 dS m^{-1} – Furlani	5.44 ± 0.49b	0.40 ± 0.05c	7.94 ± 0.96c	992.50 ± 120.06c	0.033 ± 0.002b	0.590 ± 0.052b	73.64 ± 6.44b	92.61 ± 0.35a	45.56 ± 7.00b	621.83 ± 85.19a	37.40 ± 4.75b
1.0 dS m^{-1} – Furlani	6.79 ± 0.61a	0.47 ± 0.03b	9.35 ± 0.58b	1169.06 ± 72.28b	0.034 ± 0.002b	0.641 ± 0.039b	80.05 ± 4.90b	93.11 ± 0.19a	37.64 ± 1.95c	543.40 ± 29.63b	31.43 ± 2.17c
SD											
5 seeds	5.66 ± 0.19A	0.31 ± 0.03B	6.14 ± 0.53B	767.75 ± 66.38B	0.026 ± 0.002B	0.475 ± 0.037B	59.29 ± 4.59B	91.96 ± 0.29A	61.34 ± 6.44A	751.43 ± 71.02A	36.16 ± 3.50B
10 seeds	5.66 ± 0.30A	0.49 ± 0.02A	9.79 ± 0.49A	1224.12 ± 61.39A	0.038 ± 0.001A	0.752 ± 0.015A	93.78 ± 1.83A	92.01 ± 0.23A	38.12 ± 0.97B	469.87 ± 4.72B	45.02 ± 0.59A
EC	**	**	**	**	**	**	**	**	**	**	**
SD	ns	**	**	**	**	**	**	ns	**	**	**
EC × SD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV_{EC} (%)	12.44	14.23	14.20	14.20	13.94	12.00	12.11	0.64	18.30	15.62	15.84
CV_{SD} (%)	13.55	17.52	17.63	17.63	15.48	14.22	14.21	0.48	16.45	17.04	13.54

SV – source of variation; CV_{EC} and CV_{SD} – coefficients of variation of the errors in main plots and subplots, respectively; values represent mean ± standard deviation (*n* = 4); lowercase letters compare the means of EC levels by Scott-Knott test ($p \leq 0.05$) and uppercase letters compare the means of SD by Tukey's test ($p \leq 0.05$); ** – significant at $p \leq 0.01$ and ns – not significant by F-test.

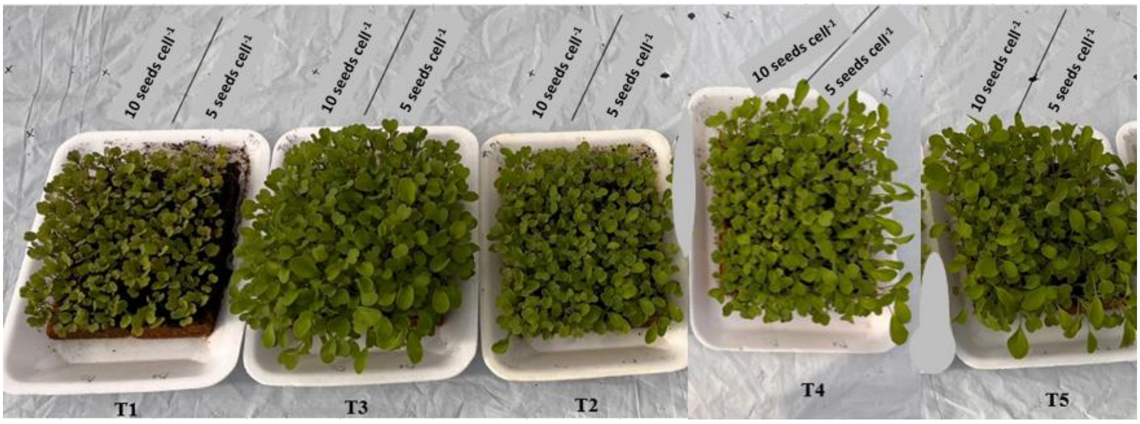

Figure 1: Visual aspect of rocket microgreens grown at two seed density and different levels of electrical conductivity (EC) of water or nutrient solutions. T1 – EC of water of 0.3 dS m^{-1}; T2 and T3 – nutrient solutions with EC of 0.6 and 1.2 dS m^{-1} at 50 and 100% concentrations of "Flex mudas 1" and "Flex mudas 2" Plantpar® compounds; T4 and T5 – nutrient solutions with EC of 0.5 and 1.0 dS m^{-1} at 25 and 50% concentrations, as recommended by Furlani et al. (1999).

Results obtained under cultivation with ECsol of 1.2 dS m^{-1} corroborate Wieth et al. (2021) when cultivating rocket microgreens with phenolic foam as a substrate. In the mentioned study, irrigation under higher ECsol of 2.0 dS m^{-1} did increase fresh biomass compared to 1.2 dS m^{-1}. Microgreen productions were 2.4-fold higher under the respective ECsol levels than under ECw (rainwater, ~ 0 dS m^{-1}). Another study with red cabbage microgreens by Wieth et al. (2019), under ECsol of 2.0 dS m^{-1}, showed a fresh biomass gain of around 21% compared to 1.2 dS m^{-1}. These investigations had duration of ten days in a greenhouse (with natural lighting) in the summer and winter, respectively, in Brazil.

Also in Brazil, Lerner et al. (2024) evaluated rocket microgreens under seeding densities (50, 100, 150, and 200 g m^{-2}) and ECsol levels (0.15, 1.00, 2.00, and 3.00 dS m^{-1}) in two cultivation cycles (winter and spring). The best rocket responses occurred under ECsol of 1.00 dS m^{-1} when grown at densities of 150 and 175 g m^{-2} for winter and spring, respectively.

Although microgreen cultivation takes only a few days (between two and three weeks from sowing), these findings reinforce the relevance of using nutrient formulations at adequate levels according to the cultivated species (Palmitessa et al., 2020; Petropoulos et al., 2021; Li et al., 2023). Previous studies irrigated rocket under ECsol levels of 1.2 dS m^{-1} (Bulgari et al., 2017), 2.6 dS m^{-1} (Kong et al., 2019b), and 1.4 dS m^{-1} (Kong et al., 2023). El-Nakhel et al. (2021) used an even lower ECsol (0.4 dS m^{-1}, with Hoagland nutrient solution at a 25% concentration). At this level, the fresh biomass gain of rocket microgreens was approximately 85% relative to irrigation with only distilled water (without nutrients). The study was performed in Italy in a growth chamber under controlled conditions (light intensity of 300 μmol m^{-2} s^{-1} and temperatures of 24/18°C during the day and night, respectively), using trays filled with a substrate (a mix of peat moss) for 16 days.

Similarly, an experiment in Denmark with three other species of the *Brassicaceae* family (kohlrabi, mustard, and radish) harvested eight days after sowing showed fresh biomass gains according to the quality of light inside the growth chamber, ranging between 1.4- and 2.0-fold higher by irrigating with solutions (ECsol of 1.86 and 1.81 dS m^{-1} at the first and second cultivation cycle, respectively) than using only water (ECw of 0.81 and 0.86 dS m^{-1}, respectively) (Cowden et al., 2024).

The highest SDM means occurred under the highest ECsol level (1.2 dS m^{-1}) (Table 1). The three other cultivation conditions with solutions (ECsol of 0.5, 0.6, and 1.0 dS m^{-1}) showed statistically similar SDM means based on the experimental unit (production for 20 phenolic foam cells of 2×2×2 cm, corresponding to an area of 80 cm^2) and extrapolating to 1 m^2. These findings have reflected on SWC; for instance, regardless of the ECsol level using the formulation by Furlani et al. (1999), the values did not statistically differ from the highest ECsol level.

The lowest WUE means obtained under ECsol levels of 1.0 and 1.2 dS m^{-1} (statistically similar) agree with biomass accumulation (Table 1). That is because the expression of this variable represents the required amount of water volume to produce 1 kg of biomass. Under these conditions, this case produced around 37 and 526 L kg^{-1} on average for WUE based on SFM and SDM, respectively. The WUE_{SFM} means obtained under ECsol of 0.5 and 0.6 dS m^{-1} were statistically equivalent, similar to SFM. As expected from lower SFM productions, ECw recorded the highest water demand (74.13 L) to produce 1 kg of fresh biomass. The WUE_{SDM} means were statistically similar at the lowest ECsol and ECw levels.

As discussed, the fresh biomass production of three species of the *Brassicaceae* family (kohlrabi, mustard, and radish) (Cowden et al., 2024), cultivated for eight days and irrigated with solutions, required lower water volumes (between 10.60 and 11.78 L kg^{-1}, according to the quality of light inside the growth chamber) than using only water (between 15.84 and 21.35 L kg^{-1}).

SFM followed this behavior, as the assessment of the required seed mass to produce 1 kg of fresh biomass under ECsol levels of 1.0 and 1.2 dS m^{-1} (statistically similar) recorded the lowest quantitative values - 29.62 g on average (Table 1). Based on these conditions, 1 kg of rocket microgreen seeds provides an estimated fresh biomass production of approximately 33.8 kg. Similarly, 1 kg of seeds yields an estimated fresh biomass production of approximately 15.8 kg when cultivated with only irrigation water. That means 63.26 g of seeds were required to produce 1 kg of fresh biomass.

As expected, a higher seeding density (10 seeds $cell^{-1}$) increased SFM by 58.06, 59.61, and 59.44% per cell, per 20 cells, and per m^2, and SDM by 54.17, 58.23, and 58.17%, respectively, compared to the lowest density (5 seeds $cell^{-1}$). Consequently, higher densities required lower water volumes to produce 1 kg of biomass, by 38.12 and 469.87 L for SFM and SDM (Table 1). Lower densities needed 61 and 60% more water to produce 1 kg of biomass. On average, SWC was 92%, regardless of density.

The seeding density of microgreens depends on the plant species for cultivation (Arya et al., 2023; Rusu et al., 2023). Usually, sowing recommendations are printed on the packaging of purchased seeds. However, seed quantitative values often need adjustments to meet local specifications, such as lighting conditions (artificial or natural light), cultivation substrate, and growth medium humidity conditions (maintenance with nutrient solutions at different concentrations). Therefore, studies have been performed with radish (Thuong and Gia, 2020) under different seeding densities combined with substrates and with kohlrabi, mustard, and radish (Cowden et al., 2024) under light intensities and fertilization.

The present study analyzed the seed mass required to produce 1 kg of fresh biomass with 10 seeds $cell^{-1}$, demonstrating a higher seed requirement of approximately 25% than cultivation with 5 seeds $cell^{-1}$. These findings may demonstrate that the 100% increase in seed amounts (from 5 to 10 seeds $cell^{-1}$) did not proportionally correspond to biomass accumulation, reaching approximately 60% for SFM. This behavior must be expected because, individually, the increased number of seedlings per unit area promotes a lower biomass accumulation; therefore, depending on the seeding density increase, it does not guarantee biomass gains per unit area. According to Cowden et al. (2024), 50% increase in the number of kohlrabi, mustard, and radish seeds, represented approximately 37% higher fresh biomass production.

These findings re-emphasize the relevance of studies on this topic because, at first, sowing at high densities demands more seeds, consequently increasing costs. Conversely, biomass production per area unit is higher, favored by the lower substrate use (the present study applied phenolic foam). Consequently, a smaller production area promotes smaller evapotranspiration losses (evaporation losses prevail before the seedlings fully cover the substrate), requiring a lower volume of water plus nutrients, for instance, to produce 1 kg of biomass, as described in this study.

The interaction between EC levels (water or nutrient solutions) and seeding densities did not significantly influence ($p > 0.05$) the potassium (K^+), sodium (Na^+), and chloride (Cl^-) contents (Table 2). These elements experienced significant changes ($p < 0.01$) from the isolated effect of EC.

Table 2: Results of analysis of variance and means for potassium (K^+), sodium (Na^+), and chloride ($Cl^–$) contents in rocket microgreens grown at two seed density (SD) and different levels of electrical conductivity (EC) of water or nutrient solutions

SV	K^+	Na^+	$Cl^–$
		g kg^{-1} DM	
EC			
0.3 dS m^{-1}	22.67 ± 1.93c	0.096 ± 0.011a	20.61 ± 1.52a
0.6 dS m^{-1} – Plantpar	40.35 ± 3.75b	0.045 ± 0.001b	14.11 ± 1.68b
1.2 dS m^{-1} – Plantpar	51.29 ± 8.55a	0.044 ± 0.000b	17.35 ± 2.30b
0.5 dS m^{-1} – Furlani	40.27 ± 2.28b	0.045 ± 0.001b	14.71 ± 2.18b
1.0 dS m^{-1} – Furlani	48.54 ± 4.32a	0.090 ± 0.001a	16.94 ± 1.64b
SD			
5 seeds	42.15 ± 1.81A	0.066 ± 0.004A	17.41 ± 0.26A
10 seeds	39.09 ± 3.59A	0.062 ± 0.001A	16.07 ± 0.99A
EC	**	**	**
SD	ns	ns	ns
EC × SD	ns	ns	ns
CV$_{EC}$ (%)	17.31	10.63	17.48
CV$_{SD}$ (%)	17.63	11.59	21.97

SV – source of variation; CV$_{EC}$ and CV$_{SD}$ – coefficients of variation of the errors in main plots and subplots, respectively; values represent mean ± standard deviation ($n = 4$); lowercase letters compare the means of EC levels by Scott-Knott test ($p \leq 0.05$) and uppercase letters compare the means of SD by Tukey's test ($p \leq 0.05$); ** – significant at $p \leq 0.01$ and ns – not significant by F-test.

Leafy vegetables comprise essential mineral sources for human health (Kathi et al., 2022; Uher et al., 2023; Tavan et al., 2024). The present study recorded the highest K^+ accumulation (on average 49.93 g kg^{-1} DM) under the highest ECsol levels (1.0 and 1.2 dS m^{-1}), approximately 24% higher than ECsol levels of 0.5 and 0.6 dS m^{-1} and 120% higher than ECw, reinforcing once more the relevance of using formulations with adequate nutrient levels for growing microgreens, consequently accumulating in their tissues. Tavan et al. (2024) applied a nutrient solution (NPK – 23:3.95:14) with half the concentration (ECsol not informed) to wild cabbage microgreens, recording K^+ contents between 24.7 and 32.0 g kg^{-1} DM without and with selenium applied to the solution at 40 μM, respectively. The study used hemp-felt mats as a cultivation substrate under controlled conditions (air temperature of 22.5°C and relative humidity between 65 and 70%). Other studies demonstrated K^+ as the most concentrated macronutrient in different microgreen species (Pinto et al., 2015; Xiao et al., 2016; Bulgari et al., 2017; Pannico et al., 2020).

The amount of this nutrient in the supply water (ECw of 0.3 dS m^{-1}) promoted higher Na^+ accumulation in rocket microgreens with this treatment and under ECsol of 1.0 dS m^{-1}. This higher Na^+ accumulation under the respective ECsol level may have been due to molybdenum use, provided as sodium molybdate. This also explains the Na^+ accumulation in the other treatments, showing statistically similar means. The highest $Cl^–$ accumulation in rocket microgreen tissues also occurred under ECw. The other treatments showed statistically equivalent means.

Table 3 demonstrates Pearson's correlation matrix, describing the degree of correlation between the evaluated variables in rocket microgreens in 14 cultivation days. The correlation coefficients (r) were over 0.6, and SH growth positively and significantly correlated ($p < 0.01$) to SFM, SWC, and K^+. Considering r values in the same magnitude, SH negatively correlated to WUE$_{SFM}$, SM, and Na^+. SFM positively correlated to SDM (r = 0.948), SWC (r = 0.623), and K^+ (r = 0.589), but WUE$_{SFM}$ (r = 0.897), WUE$_{SDM}$ (r = 0.849), SM ((r = 0.534), and Na^+ (r = 0.644) showed negative correlations. SDM negatively correlated to WUE$_{SFM}$ (r = 0.838), WUE$_{SDM}$ (r = 0.920), and Na^+ (r = 0.589). SWC recorded negative correlations to WUE$_{SFM}$ (r = 0.697) and SM (r = 0.840) and a positive correlation to K^+ (r = 0.794). WUE$_{SFM}$ positively correlated to WUE_{SDM} (r = 0.890) and SM (r = 0.540), and WUE_{SDM} behaved similarly regarding Na^+ (r = 0.589). SM negatively correlated to K^+ (r = 0.838) and positively to Na^+ (r = 0.582). K^+ negatively correlated to Na^+ (r = 0.528).

Table 3: Pearson's correlation coefficients (r) for the studied parameters including seedlings height (SH), seedlings fresh matter (SFM), seedlings dry matter (SDM), seedlings water content (SWC), water use efficiency based on SFM (WUE_{SFM}) and SDM (WUE_{SDM}), seed mass (SM) to produce 1 kg of SFM, and contents of potassium (K^+), sodium (Na^+), and chloride (Cl^-) of rocket microgreens

Variables	SH	SFM	SDM	SWC	WUE_{SFM}	WUE_{SDM}	SM	K^+	Na^+	Cl^-
SH	1	0.611**	0.467**	0.700**	–0.622**	–0.403**	–0.739**	0.702**	–0.602**	–0.252$^{\text{ns}}$
SFM		1	0.948**	0.623**	–0.897**	–0.849**	–0.534**	0.589**	–0.644**	–0.317$^{\text{ns}}$
SDM			1	0.366*	–0.838**	–0.920**	–0.308$^{\text{ns}}$	0.374*	–0.589**	–0.272$^{\text{ns}}$
SWC				1	–0.697**	–0.313$^{\text{ns}}$	–0.840**	0.794**	–0.496**	–0.447**
WUE_{SFM}					1	0.890**	0.540**	–0.516**	0.659**	0.355*
WUE_{SDM}						1	0.228$^{\text{ns}}$	–0.234$^{\text{ns}}$	0.589**	0.156$^{\text{ns}}$
SM							1	–0.838**	0.582**	0.393*
K^+								1	–0.528**	–0.375*
Na^+									1	0.216$^{\text{ns}}$
Cl^-										1

* and ** – significant at $p \leq 0.05$ and at $p \leq 0.01$, respectively, and ns – not significant by t-test.

Conclusions

The present study on rocket microgreens cultivation evaluated the interaction between levels of electrical conductivity – EC (water or nutrient solutions) and seeding densities. The best responses of rocket microgreens occurred under higher solution EC levels (1.0 and 1.2 dS m^{-1}) produced with different formulations.

Microgreens showed higher yield with 10 seeds $cell^{-1}$, consequently consuming lower volume of water.

Acknowledgments

We thank the Post Graduate Program in Agricultural Engineering (PPGEA) of the Federal University of Recôncavo da Bahia, Brazil for providing necessary infrastructure facilities for the study.

References

Arya, K. S.; Kutty, M. S.; Pradeepkumar, T. Microgreens of tropical edible-seed species, an economical source of phytonutrients- insights into nutrient content, growth environment and shelf life. Future Foods, v. 8, 100262, 2023. https://doi.org/10.1016/j.fufo.2023.100262

Bhaswant, M.; Shanmugam, D. K.; Miyazawa, T.; Abe, C.; Miyazawa, T. Microgreens—A comprehensive review of bioactive molecules and health benefits. Molecules, v. 28, n. 2, 867, 2023. https://doi.org/10.3390/molecules28020867

Bulgari, R.; Baldi, A.; Ferrante, A.; Lenzi, A. Yield and quality of basil, Swiss chard, and rocket microgreens grown in a hydroponic system. New Zealand Journal of Crop and Horticultural Science, v. 45, n. 2, p. 119-129, 2017. https://doi.org/10.1080/01140671.2016.1259642

Bulgari, R.; Negri, M.; Santoro, P.; Ferrante, A. Quality evaluation of indoor-grown microgreens cultivated on three different substrates. Horticulturae, v. 7, n. 5, 96, 2021. https://doi.org/10.3390/horticulturae7050096

Corrado, G.; Pannico, A.; Zarrelli, A.; Kyriacou, M. C.; De Pascale, S.; Rouphael, Y. Macro and trace element mineral composition of six hemp varieties grown as microgreens. Journal of Food Composition and Analysis, v. 114, 104750, 2022. https://doi.org/10.1016/j.jfca.2022.104750

Cowden, R. J.; Markussen, B.; Ghaley, B. B.; Henriksen, C. B. The effects of light spectrum and intensity, seeding density, and fertilization on biomass, morphology, and resource use efficiency in three species of *Brassicaceae* microgreens. Plants, v. 13, n. 1, 124, 2024. https://doi.org/10.3390/plants13010124

Di Gioia, F.; Hong, J. C.; Pisani, C.; Petropoulos, S. A.; Bai, J.; Rosskopf, E. N. Yield performance, mineral profile, and nitrate content in a selection of seventeen microgreen species. Frontiers in Plant Science, v. 14, 1220691, 2023. https://doi.org/10.3389/fpls.2023.1220691

El-Nakhel, C.; Pannico, A.; Graziani, G.; Kyriacou, M. C.; Gaspari, A.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Nutrient supplementation configures the bioactive profile and production characteristics of three *Brassica* L. microgreens species grown in peat-based media. Agronomy, v. 11, n. 2, 346, 2021. https://doi.org/10.3390/agronomy11020346

Furlani, P. R.; Silveira, L. C. P.; Bolonhezi, D.; Faquin, V. Cultivo hidropônico de plantas. Campinas: Instituto Agronômico, 1999. 52p. (Boletim Técnico, 180).

Fussy, A.; Papenbrock, J. An overview of soil and soilless cultivation techniques—chances, challenges and the neglected question of sustainability. Plants, v. 11, n. 9, 1153, 2022. https://doi.org/10.3390/plants11091153

Gonnella, M.; Renna, M. The evolution of soilless systems towards ecological sustainability in the perspective of a circular economy. Is it really the opposite of organic agriculture? Agronomy, v. 11, n. 5, 950, 2021. https://doi.org/10.3390/agronomy11050950

Kathi, S.; Laza, H.; Singh, S.; Thompson, L.; Li, W.; Simpson, C. Increasing vitamin C through agronomic biofortification of arugula microgreens. Scientific Reports, v. 12, 13093, 2022. https://doi.org/10.1038/s41598-022-17030-4

Kong, Y.; Kamath, D.; Zheng, Y. Blue versus red light can promote elongation growth independent of photoperiod: A study in four *Brassica* microgreens species. HortScience, v. 54, n. 11, p. 1955-1961, 2019a. https://doi.org/10.21273/HORTSCI14286-19

Kong, Y.; Masabni, J.; Niu, G. Effect of temperature variation and blue and red LEDs on the elongation of arugula and mustard microgreens. Horticulturae, v. 9, n. 5, 608, 2023. https://doi.org/10.3390/horticulturae9050608

Kong, Y.; Schiestel, K.; Zheng, Y. Pure blue light effects on growth and morphology are slightly changed by adding low-level UVA or far-red light: A comparison with red light in four microgreen species. Environmental and Experimental Botany, v. 157, p. 58-68, 2019b. https://doi.org/10.1016/j.envexpbot.2018.09.024

Kyriacou, M. C.; El-Nakhel, C.; Pannico, A.; Graziani, G.; Soteriou, G. A.; Giordano, M.; Zarrelli, A.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Genotype-specific modulatory effects of select spectral bandwidths on the nutritive and phytochemical composition of microgreens. Frontiers in Plant Science, v. 10, 1501, 2019. https://doi.org/10.3389/fpls.2019.01501

Lerner, B. L.; Strassburger, A. S.; Schäfer, G. Cultivation of arugula microgreens: seed densities and electrical conductivity of nutrient solution in two growing seasons. Bragantia, v. 83, e20230183, 2024. https://doi.org/10.1590/1678-4499.20230183

Li, T.; Arthur, J. D.; Bi, G. Shoot yield and mineral nutrient concentrations of six microgreens in the Brassicaceae family affected by fertigation rate. Horticulturae, v. 9, n. 11, 1217, 2023. https://doi.org/10.3390/horticulturae9111217

Li, T.; Lalk, G. T.; Arthur, J. D.; Johnson, M. H.; Bi, G. Shoot production and mineral nutrients of five microgreens as affected by hydroponic substrate type and post-emergent fertilization. Horticulturae, v. 7, n. 6, 129, 2021a. https://doi.org/10.3390/horticulturae7060129

Li, T.; Lalk, G. T.; Bi, G. Fertilization and pre-sowing seed soaking affect yield and mineral nutrients of ten microgreen species. Horticulturae, v. 7, v. 2, 14, 2021b. https://doi.org/10.3390/horticulturae7020014

Mir, Y. H.; Mir, S.; Ganie, M. A.; Shah, A. M.; Majeed, U.; Chesti, M. H.; Mansoor, M.; Irshad, I.; Javed, A.; Sadiq, S.; Wani, F. J. Soilless farming: An innovative sustainable approach in agriculture. The Pharma Innovation Journal, v. 11, n. 6, p. 2663-2675, 2022.

Moraru, P. I.; Rusu, T.; Mintas, O. S. Trial protocol for evaluating platforms for growing microgreens in hydroponic conditions. Foods, v. 11, n. 9, 1327, 2022. https://doi.org/10.3390/foods11091327

Murphy, C. J.; Pill, W. G. Cultural practices to speed the growth of microgreen arugula (roquette; *Eruca vesicaria* subsp. *sativa*). The Journal of Horticultural Science and Biotechnology, v. 85, n. 3, p. 171-176, 2010. https://doi.org/10.1080/14620316.2010.11512650

Palmitessa, O. D.; Renna, M.; Crupi, P.; Lovece, A.; Corbo, F.; Santamaria, P. Yield and quality characteristics of *Brassica* microgreens as affected by the NH_4:NO_3 molar ratio and strength of the nutrient solution. Foods, v. 9, n. 5, 677, 2020. https://doi.org/10.3390/foods9050677

Pannico, A.; El-Nakhel, C.; Graziani, G.; Kyriacou, M. C.; Giordano, M.; Soteriou, G. A.; Zarrelli, A.; Ritieni, A.; De Pascale, S.; Rouphael, Y. Selenium biofortification impacts the nutritive value, polyphenolic content, and bioactive constitution of variable microgreens genotypes. Antioxidants, v. 9, n. 4, 272, 2020. https://doi.org/10.3390/antiox9040272

Parkes, M. G.; Tovar, J. P. C.; Dourado, F.; Domingos, T.; Teixeira, R. F. M. Life cycle assessment of a prospective technology for building-integrated production of broccoli microgreens. Atmosphere, v. 13, n. 8, 1317, 2022. https://doi.org/10.3390/atmos13081317

Partap, M.; Sharma, D.; HN, D.; Thakur, M.; Verma, V.; Ujala.; Bhargava, B. Microgreen: A tiny plant with superfood potential. Journal of Functional Foods, v. 107, 105697, 2023. https://doi.org/10.1016/j.jff.2023.105697

Petropoulos, S. A.; El-Nakhel, C.; Graziani, G.; Kyriacou, M. C.; Rouphael, Y. The effects of nutrient solution feeding regime on yield, mineral profile, and phytochemical composition of spinach microgreens. Horticulturae, v. 7, n. 7, 162, 2021. https://doi.org/10.3390/horticulturae7070162

Pinto, E.; Almeida, A. A.; Aguiar, A. A.; Ferreira, I. M. P. L. V. O. Comparison between the mineral profile and nitrate content of microgreens and mature lettuces. Journal of Food Composition and Analysis, v. 37, p. 38-43, 2015. https://doi.org/10.1016/j.jfca.2014.06.018

Rusu, T.; Moraru, P. I.; Mintaș, O. S.; Cărbu-Nar, M. M.; Pop, H.; Lupuț, I. N. Basil and lettuce microgreens production in low-cost hydroponic installations, under operational and semi-controlled conditions. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology, v. 80, n. 2, p. 95-107, 2023. https://doi.org/10.15835/buasvmcn-fst:2023.0008

Silva, M. G.; Costa, I. P.; Alves, L. S.; Soares, T. M.; Gheyi, H. R. Coriander cultivation under different nutrient solution depths in hydroponic systems: a comparison between conventional DFT and adapted DFT with PVC pipes. Water Resources and Irrigation Management, v. 12, n. 1-3, p. 29-43, 2023. https://doi.org/10.19149/wrim.v12i1-3.3077

Silva, M. G.; Gheyi, H. R.; Silva, L. L.; Souza, T. T.; Silva, P. C. C.; Queiroz, L. A.; Santos, T. S.; Soares, T. M. Evaluation of salt and root-zone temperature stresses in leafy vegetables using hydroponics as a clean production cultivation technique in northeastern Brazil. Horticulture, Environment, and Biotechnology, v. 65, n. 1, p. 95-118, 2024. https://doi.org/10.1007/s13580-023-00547-6

Sparks, R. E.; Stwalley III, R. M. Design and testing of a modified hydroponic shipping container system for urban food production. International Journal of Applied Agricultural Sciences, v. 4, n. 4, p. 93-102, 2018. https://doi.org/10.11648/j.ijaas.20180404.11

Tavan, M.; Wee, B.; Fuentes, S.; Pang, A.; Brodie, G.; Viejo, C. G.; Gupta, D. Biofortification of kale microgreens with selenate-selenium using two delivery methods: Selenium-rich soilless medium and foliar application. Scientia Horticulturae, v. 323, 112522, 2024. https://doi.org/10.1016/j.scienta.2023.112522

Tilahun, S.; Baek, M. W.; An, K.-S.; Choi, H. R.; Lee, J. H.; Hong, J. S.; Jeong, C. S. Radish microgreens produced without substrate in a vertical multi-layered growing unit are rich in nutritional metabolites. Frontiers in Plant Science, v. 14, 1236055, 2023. https://doi.org/10.3389/fpls.2023.1236055

Thepsilvisut, O.; Sukree, N.; Chutimanukul, P.; Athinuwat, D.; Chuaboon, W.; Poomipan, P.; Vachirayagorn, V.; Pimpha, N.; Chutimanukul, P.; Ehara, H. Efficacy of agricultural and food wastes as the growing media for sunflower and water spinach microgreens production. Horticulturae, v. 9, n. 8, 876, 2023. https://doi.org/10.3390/horticulturae9080876

Thuong, V. T.; Gia, M. H. Effects of growing substrates and seed density on yield and quality of radish (*Raphanus sativus*) microgreens. Research on Crops, v. 21, n. 3, p. 579-586, 2020. https://doi.org/10.31830/2348-7542.2020.091

Uher, S. F.; Radman, S.; Opačić, N.; Dujmović, M.; Benko, B.; Lagundžija, D.; Mijić, V.; Prša, L.; Babac, S.; Žlabur, J. Š. Alfalfa, cabbage, beet and fennel microgreens in floating hydroponics—perspective nutritious food? Plants, v. 12, n. 11, 2098, 2023. https://doi.org/10.3390/plants12112098

Velazquez-Gonzalez, R. S.; Garcia-Garcia, A. L.; Ventura-Zapata, E.; Barceinas-Sanchez, J. D. O.; Sosa-Savedra, J. C. A review on hydroponics and the technologies associated for medium- and small-scale operations. Agriculture, v. 12, n. 5, 646, 2022. https://doi.org/10.3390/agriculture12050646

Vrkić, R.; Žlabur, J. Š.; Dujmović, M.; Benko, B. Can LED lighting be a sustainable solution for producing nutritionally valuable microgreens? Horticulturae, v. 10, n. 3, 249, 2024. https://doi.org/10.3390/horticulturae10030249

Wieth, A. R.; Pinheiro, W. D.; Duarte, T. S. Purple cabbage microgreens grown in different substrates and nutritive solution concentrations. Revista Caatinga, v. 32, n. 4, p. 976-985, 2019. https://doi.org/10.1590/1983-21252019v32n414rc

Wieth, A. R.; Pinheiro, W. D.; Duarte, T. S. Commercial substrates and nutrient concentrations in the production of arugula microgreens. Agronomía Colombiana, v. 39, n. 1, p. 5-11, 2021. https://doi.org/10.15446/agron.colomb.v39n1.87290

Xiao, Z.; Codling, E. E.; Luo, Y.; Nou, X.; Lester, G. E.; Wang, Q. Microgreens of Brassicaceae: Mineral composition and content of 30 varieties. Journal of Food Composition and Analysis, v. 49, p. 87-93, 2016. http://dx.doi.org/10.1016/j.jfca.2016.04.006

Xiao, Z.; Lester, G. E.; Park, E.; Saftner, R. A.; Luo, Y.; Wang, Q. Evaluation and correlation of sensory attributes and chemical compositions of emerging fresh produce: Microgreens. Postharvest Biology and Technology, v. 110, p. 140-148, 2015. http://dx.doi.org/10.1016/j.postharvbio.2015.07.021

Ying, Q.; Kong, Y.; Jones-Baumgardt, C.; Zheng, Y. Responses of yield and appearance quality of four *Brassicaceae* microgreens to varied blue light proportion in red and blue light-emitting diodes lighting. Scientia Horticulturae, v. 259, 108857, 2020. https://doi.org/10.1016/j.scienta.2019.108857