https://doi.org/10.1590/1678-4499.20230183

CROP PRODUCTION
Article

Cultivation of arugula microgreens: seed densities and electrical conductivity of nutrient solution in two growing seasons

Betina Luiza Lerner[1,*], Andre Samuel Strassburger[1], Gilmar Schäfer[1]

1. Universidade Federal do Rio Grande do Sul – Departamento de Horticultura e Silvicultura – Porto Alegre (RS), Brazil.

Received: Aug. 30, 2023 | **Accepted:** Jan. 19, 2024

Section Editor: Gabriel Constantino Blain

***Corresponding author:** betinalerner@hotmail.com

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

ABSTRACT: Microgreens are young plants of vegetables crops that have stood out for their potential in culinary and their nutritional content. However, cultural practices such as seed density and fertilization methods have not been standardized yet. The aim of this study was to evaluate the seed density and electrical conductivity of nutrient solution in a soilless system of arugula microgreens in two growing seasons. The experiment was carried out in Porto Alegre, RS, Brazil, during winter and spring. The experimental design adopted was randomized blocks, with a factorial arrangement (4 × 4) formed by four sowing densities (50, 100, 150, and 200 $g \cdot m^{-2}$) and four levels of electrical conductivity, being 0.15, 1, 2, and 3 $mS \cdot cm^{-1}$. The evaluated characteristics were shoot height, shoot fresh and dry matter yield, and total soluble solids index. Growing microgreens without a nutrient solution is not recommended. The increase of electrical conductivity of nutrient solution and seed density promoted higher values of shoot dry matter yield and total soluble solids index. In winter, the best results were obtained using 150 $g \cdot m^{-2}$ of seeds at an electrical conductivity of 1 $mS \cdot cm^{-1}$. In spring, 175 $g \cdot m^{-2}$ of seeds was necessary, with a minimal electrical conductivity of 1 $mS \cdot cm^{-1}$.

Key words: *Eruca sativa* L., microgreens, electrical conductivity, soilless cultivation, protect environment.

INTRODUCTION

Freshly consumed foods, as microgreens, which are young plants, usually from vegetable species, have garnered attention for their culinary utility and nutritional richness. Due to their composition, with a high content of bioactive compounds, like as carotenoids and phenolic compounds (Xiao et al. 2012, Sun et al. 2013), in addition to their accessibility, microgreens can contribute to improve food quality for various populations (Di Gioia and Santamaria 2015).

These plants are harvested at the growing media level, usually when cotyledons reach full development and the first pair of true leaves begins to emerge or is partially expanded, typically within seven to 14 days post germination, depending on the species (Treadwell et al. 2010, Xiao et al. 2012). Commonly, soilless cultivation systems are used, along with the use of growing medias, preferably in a closed system (Resh 2012). However, cultural practices like as seed density and fertilization lack standardization, resulting in broad recommendations (Bulgari et al. 2017, Nolan 2019).

Cultivating microgreens demands substantial seed quantities, especially due to imprecise sowing, utilizing broadcast seeding, consequently, representing one of the main production costs. Still, there is a tendency, among most producers, to use high seed densities to maximize yield. Determining the appropriate seed density holds importance for farmers as it can help to maximize profits while using minimum amount of seeds, given their high cost (Nolan 2019). However, seed density varies according to seasonal changes, cultivation system and species, and relies on seed weight germination and desired plant population (Kyriacou et al. 2016).

Applying a nutrient solution with appropriate nutrient concentration promotes improvements in the yield and quality of microgreens (Bulgari et al. 2017). Nevertheless, nutrients uptake by plants is influenced by environmental conditions, such as temperature, humidity, and solar radiation, as well as by the species and stage of development of such crop (Resh 2012). Fluctuations in climatic conditions induce variations in plant evapotranspiration. Therefore, for greater efficiency in nutrient utilization, adjusting the nutrient solution's electrical conductivity in accordance with the season and geographical location becomes imperative (Pinheiro et al. 2021).

However, due to the recent and expanding nature of this practice, studies on microgreens, especially in Brazil, remain scarce (Bezerra et al. 2022). Hence, it is necessary to acquire comprehensive insights into their cultivation in different technological and climatic conditions. Therefore, this study aimed to identify the seed density required to achieve standardized height to facilitate harvest, as well as maximize fresh matter yield. Furthermore, it sought to encounter the electrical conductivity of nutrient solution that would promote superior agronomic results for arugula microgreens grown in a soilless recirculating system in two growing seasons, in comparison to using water alone.

MATERIALS AND METHODS

Microgreen cultivation and experimental design

The experiment was carried out on Universidade Federal do Rio Grande do Sul in the Department of Horticulture and Forestry (latitude 30°04'S and longitude 51°08'W), located in the city of Porto Alegre, RS, South of Brazil. The same experiment was conducted in two growing seasons: winter and spring.

Carolina Soil growing media (a mixture of peat, vermiculite, and carbonized rice husk) was placed in white polystyrene trays, perforated at the base (six holes of 3 mm in diameter each), without compartments and with dimensions of 18.9 cm × 9.4 cm × 2 cm, forming a layer 1.5 cm high. Sowing was done manually with arugula rocket seeds, cv. Roka, (TopSeed) deposited on the moistened substrate without subsequent covering. For winter cultivation, sowing occurred on July 28, 2021; and for spring, it took place on November 3, 2021.

Then, the trays were allocated in a germination chamber biochemical oxygen demand type, under a constant temperature of 25°C and in absence of light for 48 hours, in order to facilitate and standardize seed germination. When necessary, the trays were re-moistened with just water without fertilization. The temperature of 25 °C was chosen based on the recommendations of Ferreira et al. (2008) for germination of arugula seeds. The criteria adopted to determine germination was the appearance of the hypocotyl.

On July 30, 2021 (winter) and November 5, 2021 (spring), with seeds already germinated, the trays were transferred to rectangular pools, according to the structure proposed by Wieth et al. (2020) to produce microgreens, that were located inside a protected environment (greenhouse). The pools were built in wood and covered with double faced polyethylene film (white/black) of 100 μm, resulting in a depth of 0.07 m and a 2% slope and supported at a height of 1 m by galvanized iron benches. The greenhouse has dimensions of 5 m × 10 m and a 3-m height, and it is covered with 150-μm plastic film (LDPE). It has no temperature or light control.

For fertigation, which commenced upon transferring the trays to the pools, an intermittent sub-irrigation system was employed. The system provided cycles of the nutrient solution for 15 minutes per hour, operating from 9 a.m. to 5 p.m. with an additional irrigation cycle at night, also lasting 15 min. The system had one drain at the end of the pool, which allowed the re-conduction of the drained nutrient solution to its reservoir. Thus, a closed system was established, with no loss of nutrient solution volume through leachate.

A randomized block design was adopted, in a 4 × 4 factorial design that was composed by four seed densities and four electrical conductivities of a nutrient solution, with three replications per treatment. The seed densities used were: 50, 100, 150 and 200 $g{\cdot}m^{-2}$. The seeds were weighed on a precision analytical balance. The nutrient solution (NS) used was proposed by Santos (2010), which is indicated for the hydroponic cultivation of arugula, with the following composition (100% nutrient concentration) of macronutrients (in $mmol{\cdot}L^{-1}$): 12.38 NO^{3-}; 1.27 $H_2PO_4^-$; 3.33 SO_4^{2-}; 1.96 NH_4^+; 9.35 K^+;

3.45 Ca^{2+}; 1.05 Mg^{2+}; of micronutrients (in mg·L^{-1}): 5 Fe; 0.05 Mn; 0.09 Zn; 0.10 of B; 0.04 Cu; 0.02 of Mo. The micronutrients were maintained at standard concentration as recommended by the commercial product ConMicros Light (Conplant). For iron, the product Oligo Ferro EDDHA 6% from Van Iperen was used. Four concentrations of nutrients were tested: 0.15, 1, 2, and 3 mS·cm^{-1} (initial electrical conductivity), corresponding to 0, 50, 100 and 150% of the nutrient solution used as reference, respectively. The electrical conductivity (EC) was monitored daily using a conductivity meter AK51 (AKSO). The initial pH ranged between 5.5 and 6.

Measurements and observations

In winter, the air temperature within the protected environment ranged from 3.1 to 32.7 °C, with average maximum temperature of 27.9 °C and minimum of 9.4 °C. The relative humidity during the same period varied from 31 to 90%. Outside the protected environment, the average maximum temperature was 18 ºC and the minimum was 7.1 °C, with an average daily insolation of 5.2 hours and 0.2 mm·day^{-1} of rainfall (INMET 2022).

During spring cultivation, the air temperature ranged from 11.7 to 40.2ºC, with an average maximum temperature of 38.8 °C and a minimum of 13.3 °C. Relative humidity varied between 15 and 88%. Outside the protected environment, the average maximum temperature was 25.8 °C, and the minimum was 16.7 °C, with an average of 9 hours of daily sunshine and 2.4 mm·day^{-1} of rainfall (INMET 2022).

The harvesting process began when 80% of the microgreens displayed fully expanded cotyledons, with the beginning of the development of primary leaves. Harvest was carried out on July 6, 2021 (winter) and November 9, 2021 (spring), totaling nine days for winter cultivation cycle and seven for the spring cycle.

The shoot height at harvest (SHH) was measured using a millimeter-graduated ruler, assessing four points per tray (the average value was used), from the stem base to the top of the seedling. The shoot fresh matter yield (SFMY) was obtained per tray (178 cm^2), measured on a precision scale and converted to g·m^{-2}. For the shoot dry matter yield (SDMY), a forced air oven set at 65 °C was used until a constant weight was achieved (48–72 hours), followed by weighing on a precision scale. The total soluble solids (TSS) were quantified using Atago PAL-1 portable digital refractometer. A plant extract for this assessment was produced by grinding 20 microgreen seedlings in a porcelain mortar with pestle. The fresh mass of these 20 seedlings was weighed separately and then added to the value of shoot fresh mass, obtaining SFMY. For SDMY, the value referring to the 20 seedlings was estimated and added to the shoot dry mass value (without the 20 seedlings).

Statistical analysis

Data were subject to Shapiro-Wilk and Levene's tests to verify normality and homogeneity of variance, respectively. Subsequently, analysis of variance via the F test ($p > 0.05$) was conducted using R software. Regression analyses were performed using Sigmaplot 14.0 software (Systat Software, Inc.) ($p > 0.05$) according to the interactions identified.

RESULTS AND DISCUSSION

The analysis of variance indicated that only SHH and SFMY had significant interaction between seed density and EC of the nutrient solution in the winter period. SDMY and TSS showed independent significant effects, as well as SHH and SFMY in the spring cycle. In both growing seasons, seed density and EC of the nutrient solution influenced all characteristics analyzed.

Shoot height at harvest

Analyzing the unfolding of the interaction of the SHH with different seed densities in four EC levels during winter, notably, only the treatment utilizing water—without nutrient solution—displayed linear results (Fig. 1a). In this case, the result was a height of less than 4 cm in all seed densities evaluated. Conversely, the three other EC exhibited a quadratic result concerning seed density, with maximum values at 155 g·m^{-2} (1 mS·cm^{-1}), 130 g·m^{-2} (2 mS·cm^{-1}), and 135 g·m^{-2} (3 mS·cm^{-1}) of seeds, corresponding to heights of 4.6, 5, and 5.9 cm, respectively (calculated data).

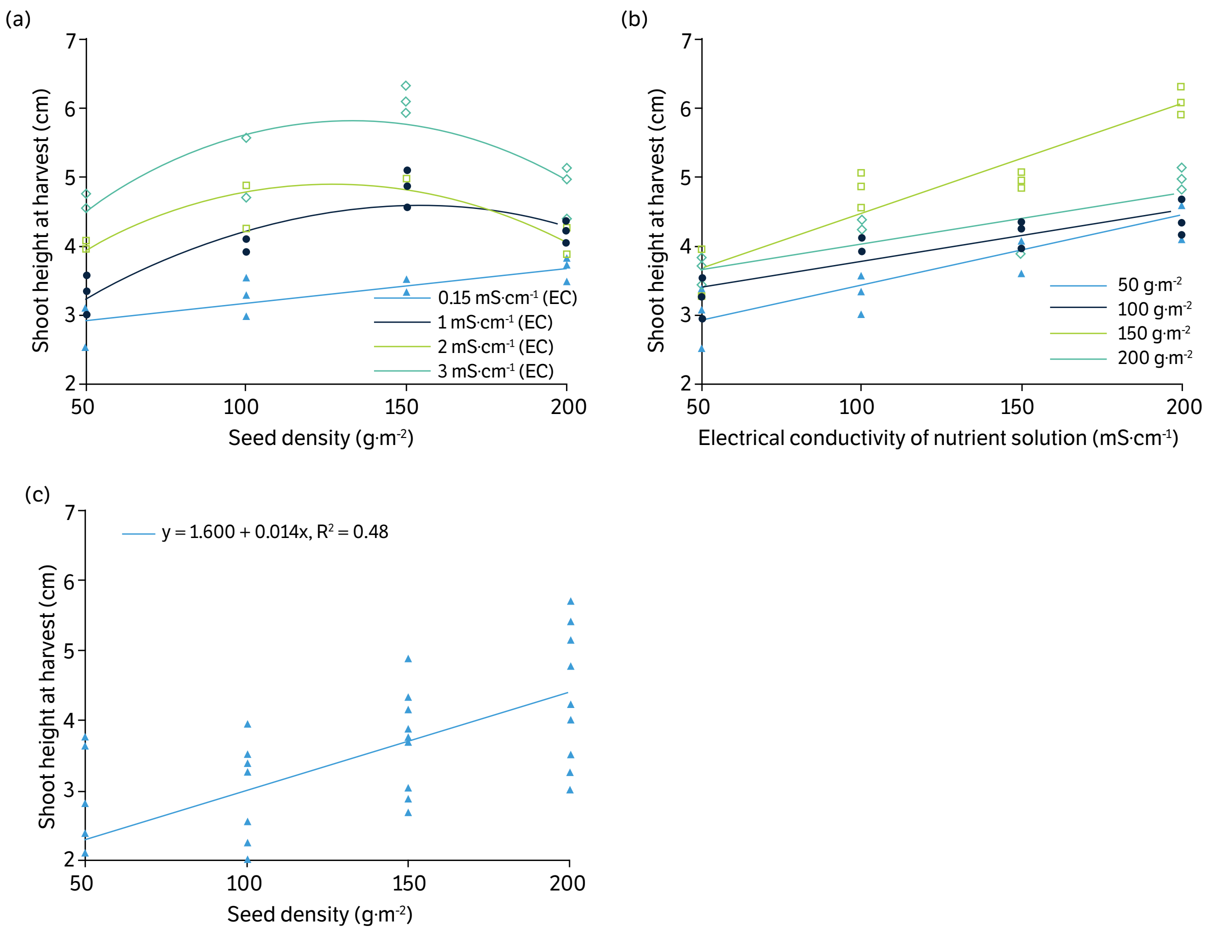

Figure 1. Arugula microgreens shoot height at harvest (cm) according to seed densities (50, 100, 150 and 200 g·m^{-2}) and electrical conductivities (0, 1, 2 and 3 mS·cm^{-1}). The observed data is represented by the points, while the trendline is the result of the equation shown in the article or in the figure. (a) Shoot height at harvest in relation to seed density of arugula microgreens at different electrical conductivities (EC) of nutrient solution in winter. (b) Shoot height at harvest in relation to EC of nutrient solution in arugula microgreens cultivation at different seed densities in winter. (c) Shoot height at harvest in relation to seed density of arugula microgreens cultivated in the spring. $P < 0{,}0001$. Porto Alegre, RS, Brazil, 2021. (a) 0.15 mS·cm^{-1} = $2.662 + 0.005x$, $R^2 = 0.67$; 1 mS·cm^{-1} = $1.564 + 0{,}040x - 0{,}000131x^2$, $R^2 = 0.81$; 2 mS·cm^{-1} = $2.321 + 0.041x + 0.000160x^2$, $R^2 = 0.75$; 3 mS·cm^{-1} = $2.370 + 0.053x - 0.0001980x^2$, $R^2 = 0.60$. (b) 50 g·m^{-2} = $2.936 + 0.507x$, $R^2 = 0.78$; 100 g·m^{-2} = $3.420 + 0.365x$, $R^2 = 0.75$; 150 g·m^{-2} = $3.670 + 0.796x$, $R^2 = 0.88$; 200 g·m^{-2} = $3.677 + 0.368x$, $R^2 = 0.68$.

The height of microgreens is determinant to execute the harvest process, often conducted manually. Investigations suggest that the higher the microgreens, the easier the harvest will be (Palmitessa et al. 2020). For the arugula microgreens, 4–5 cm of height allows the proper manual harvesting (Di Gioia and Santamaria 2015). Some authors establish a maximum height for harvesting, such as 6 cm (Senevirathne et al. 2019). This study observed that, when surpassing 6 cm, the seedlings tended to bend, due to the excessive growth of their hypocotyls, an unfavorable trait for commercialization.

During winter season, the seed density of 50 g·m^{-2} reached a minimum height of 4 cm only from 2.2 mS·cm^{-1}, approximately; the same occurred for 100 g·m^{-2} at 1.6 mS·cm^{-1}; for the treatment of 150 g·m^{-2} of seeds, in 0.5 mS·cm^{-1}; and for 200 g·m^{-2} of seeds, in 1 mS·cm^{-1}. This demonstrates that all treatments evaluated needed the supply of nutrients through nutrient solution to reach the desirable height.

It can be observed that the treatment with 150 $g{\cdot}m^{-2}$ of seeds was more responsive to the increase in EC of nutrient solution, also due to its angle of inclination of the straight line, the highest. However, this seed density demanded the least EC to attain 4 cm of height.

These results might be associated with intensified competition between plants in treatments with higher seed density, since higher densities generate competition for space and light, as verified in bunches of mature arugula plants (Gonçalves-Trevisoli et al. 2017). Considering that the densification of plants did not affect canopy health, it suggests that the increase in seed density (population) of microgreens, up to certain limits, favors plant vigor, being beneficial for characteristics such as shoot height (Lima et al. 2004, Lima et al. 2007).

For microgreens cultivated during winter, the increase of EC resulted in a linear increase in SHH for all seed densities evaluated (Fig. 1b). The treatment with 150 $g{\cdot}m^{-2}$ of seeds was superior to all three other ones from EC 0.15 $mS{\cdot}cm^{-1}$, reaching 6 cm at the highest EC tested. The treatments with 50 and 100 $g{\cdot}m^{-2}$ of seeds reached values close to 4.5-cm height at the maximum EC tested (3 $mS{\cdot}cm^{-1}$), while the seed density of 200 $g{\cdot}m^{-2}$ approached 4.8 cm height at the same EC. At the initial EC (0.15 $mS{\cdot}cm^{-1}$), only the 50 $g{\cdot}m^{-2}$ treatment did not reach a height greater than 3 cm.

During spring, SHH showed no interaction between the factors studied. Analyzing the simple effects, the increase in seed density promotes a linear height grow (Fig. 1c). There was no mathematical adjustment for nutrient concentration as a factor. So, the average of SHH for all EC tested was 3.4 cm.

Arugula microgreens grown in water during the winter did not reach the desired height, regardless of the seed density adopted. The maximum SHH reached by treatments with EC of 1 and 2 $mS{\cdot}cm^{-1}$ was less than 5 cm. Therefore, only in EC of 3 $mS{\cdot}cm^{-1}$ this value was reached, requiring about 67 $g{\cdot}m^{-2}$ of seeds. When examining the result curves, the attained value when using a nutrient solution at an EC of 2 $mS{\cdot}cm^{-1}$ (5 cm) fulfills harvest requirements, leading to reduced nutrient application expenses compared to the 3 $mS{\cdot}cm^{-1}$ treatment.

During spring, for microgreens achieve the desired minimum height, it was necessary to use approximately 175 $g{\cdot}m^{-2}$ of seeds, indicating a notably high quantity. The limited height growth may be related to the elevated air temperature recorded within the protected environment in this period (> 40 °C), which directly influences the temperature of the nutrient solution, that may harm the growth and development of plants.

Evaluating the effects of light quality and intensity on brassica microgreens, a study concluded that higher light intensity resulted in smaller microgreens, characterized by shorter hypocotyl length. This phenomenon is associated with gibberellin activity, that is, the higher the light intensity, the lower the endogenous gibberellin concentration in brassicas species (Gerovac et al. 2016). Similarly, another study found that extended periods of higher light exposure led to shorter radish microgreens due to lower hypocotyl growth (Nolan 2019). Thus, the greater availability of light during the spring, in contrast to winter, may have negatively affected the shoot growth of arugula microgreens.

Shoot fresh matter yield

For the initial EC (0.15 $mS{\cdot}cm^{-1}$), the increase in seed density resulted in a linear increase in SFMY during winter (Fig. 2a). For other EC levels, the interactions promoted quadratic relationships. The EC treatments of 2 and 3 $mS{\cdot}cm^{-1}$ reached maximum values at 165 $g{\cdot}m^{-2}$.

The interaction between EC and seed density for SFMY of arugula microgreens resulted in a linear increase during the winter (Fig. 2b). The highest SFMY value (2,069.1 $g{\cdot}m^{-2}$) was reached using 150 $g{\cdot}m^{-2}$ of seeds. This treatment presented higher SMFY values, in absolute numbers, compared to those obtained at the density of 200 $g{\cdot}m^{-2}$ and beyond, starting from 1 $mS{\cdot}cm^{-1}$.

SFMY stands as a key characteristic in determining the adequate seed density for cultivating specific microgreen species. However, there are some divergences regarding seed density (Murphy and Pill 2010, Bulgari et al. 2017, Nolan 2019), given that the cultivation environment changes across study sites, mainly concerning light and air temperature conditions.

Regarding the commercialization of microgreens, generally based on fresh matter after harvest, a value of 30 g per package can be considered adequate. Therefore, when SFMY values exceed 1,800 $g{\cdot}m^{-2}$, equivalent to 32 g per production tray (178 cm^2), they can generate significant profits for producers, when commercialized at local markets or fairs through individual trays sales.

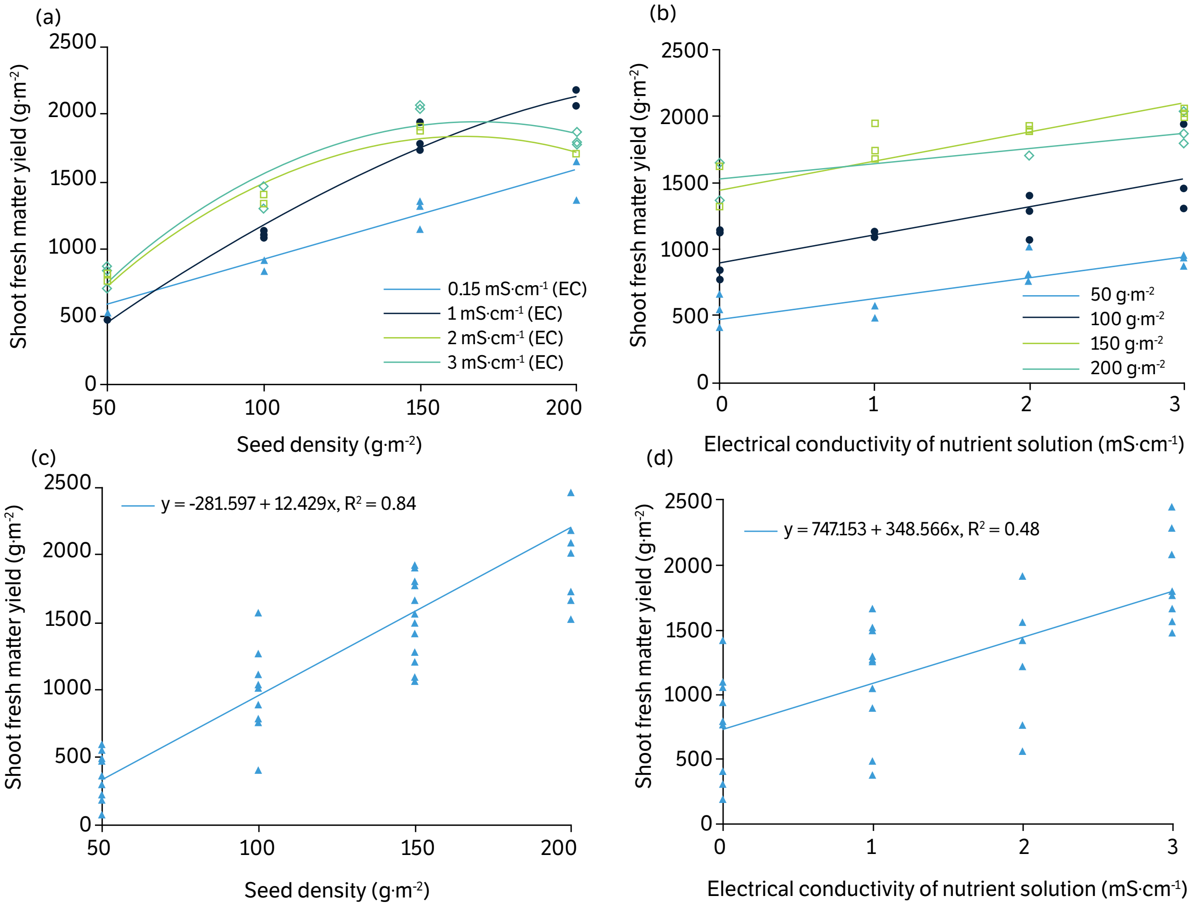

Figure 2. Arugula microgreens shoot fresh matter yield (g·m^{-2}) according to seed densities (50, 100, 150 and 200 g·m^{-2}) and electrical conductivities (0, 1, 2 and 3 mS·cm^{-1}) during winter and spring. The observed data is represented by the points, while the trendline is the result of the equation shown in the article or in the figure. (a) Shoot fresh matter yield in relation to seed density of arugula microgreens at different electrical conductivities in nutrient solution during winter. (b) Shoot fresh matter yield in relation to electrical conductivity of nutrient solution in arugula microgreens cultivation oat different seed densities during winter. (c) Shoot fresh matter yield in relation to seed density of arugula microgreens cultivated during spring. (d) Shoot fresh matter yield in relation to electrical conductivity of nutrient solution of arugula microgreens cultivated in the spring. $p < 0.0001$. Porto Alegre, RS, Brazil, 2021. (a) 0.15 mS·cm^{-1} = 259.897 + 6.598x, R^2 = 0.91; 1 mS·cm^{-1} = -427.669 + 19.665x - 0.035x^2, R^2 = 0.98; 2 mS·cm^{-1} = -478.944 + 27.582-0.084x^2, R^2 = 0.96; 3 mS·cm^{-1} = -452.817 + 28.726x - 0.086x^2, R^2 = 0.95. (b) 50 g·m^{-2} = 481.676 + 153.305x, R^2 = 0.70; 100 g·m^{-2} = 897.360 + 211.217x. R^2 = 0.64; 150 g·m^{-2} = 1435.511 + 211.189x, R^2 = 0.74; 200 g·m^{-2} = 1531.728 + 112.948x, R^2 = 0.65.

Under very similar conditions to those presented in this study, authors identified SFMY for summer-grown arugula microgreens ranging from 581 to 2,013.9 g·m^{-2}, at seed density of 100 g·m^{-2}, and Carolina Soil growing media (Wieth et al. 2021). The nutrient EC used corresponded to 0, 1.2 and 2 mS·cm^{-1}. This SFMY variance aligns with the findings of the current work, in which the variation, considering all winter treatments, was from 481.7 to 2,069.1 g·m^{-2}, and in the spring, from 339.9 to 2,204.2 g·m^{-2}.

However, when cultivated during winter, arugula microgreens at the same seed density (100 g·m^{-2}) required an EC of 3 mS·cm^{-1} to achieve 1,531 g·m^{-2} of SFMY (Fig. 2b), being this value 31% lower than that reported by other researchers, who reached a yield of 2,013.9 g·m^{-2} using an EC of 2 mS·cm^{-1} (Wieth et al. 2021). This difference might be attributed to the climatic conditions within the protected environment and seasonal variations during microgreens cultivation in both studies. Also, the duration of nutrient solution exposure varied. Wieth et al. (2021) exposed the microgreens to the NS from sowing, whereas in this study exposure began on the third day after sowing. Notably, both studies concluded that microgreens cultivation made solely in water, without nutrient solution, is not recommended.

The SFMY of microgreens in spring showed linear growth for seed density (Fig. 2c). The mathematical adjustment between SFMY and EC of nutrient solution resulted in a linearly increasing curve (Fig. 2d).

Comparing to the cultivation of arugula microgreens during summer, which reached values above 2,000 g·m^{-2} using 100 g·m^{-2} (Wieth et al. 2021), the present study required a seed density of approximately 185 g·m^{-2}. However, in this study, the harvest occurred on the seventh day, during spring, whereas the referenced authors conducted the harvest between eight and 11 days. This reduction in the crop cycle could be important to optimize the use of the protected environment, allowing greater production per area throughout the year, although the individual production of microgreens is lower in SFMY content.

Evaluating the fresh matter of shoots and sauces of mature arugula plants across four seasons, Pinheiro et al. (2021) concluded that the highest EC promoted superior results, across all seasons. Therefore, the superior SFMY of microgreens cultivated in the winter, observed at the highest EC tested (3 mS·cm^{-1}), across all seed density levels, aligns well with the expectations.

Considering the highest seed density tested, the SFMY of the spring cycle surpassed the winter cycle, reaching 2,204.2 and 2,105.3 g·m^{-2}, respectively. However, averaging the SFMY values across all tested seed densities (Fig. 2b), regardless of the NS used, the mean SFMY in winter was 1,344.5 g·m^{-2}, while during spring it was 1,272 g·m^{-2}. These results are corroborated by Nolan (2019) research, which highlighted that arugula microgreens cultivated during the winter exhibited higher average SFMY compared to those grown in summer and spring.

Shoot dry matter yield

SDMY analysis presented mathematical adjustment only for seed density, which resulted in a linear increase during winter and spring (Fig. 3). For EC, SDMY average across all treatments was 68.1 and 89.9 g·m^{-2}, during winter and spring, respectively.

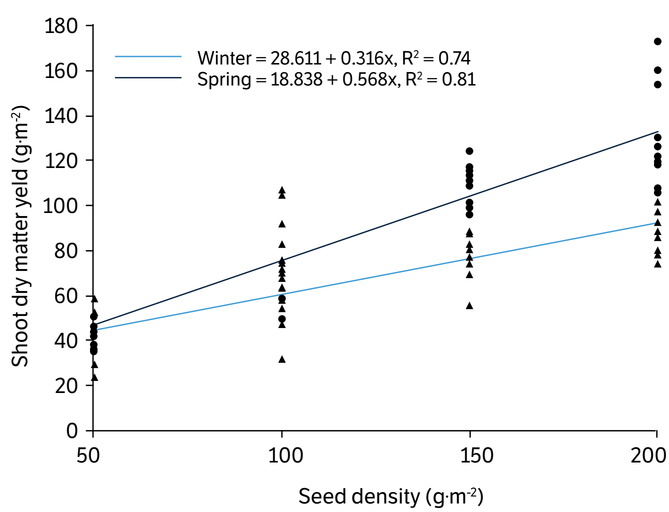

Figure 3. Shoot dry matter yield in relation to the seed density of arugula microgreens cultivated during winter and spring. $p < 0.0001$. Porto Alegre, RS, Brazil, 2021.

SDMY varied from 44.4 to 91.8 g·m^{-2} during winter and from 47.2 to 132.4 g·m^{-2} during spring. Generally, the result was alike to SFMY, with winter and spring crops displaying similar values at lower seed densities, diverging as seed densities increased. Therefore, the increase in seed density promoted higher SDMY values in both cultivation periods.

Furthermore, SDMY is influenced by seed density and EC. The highest seed density reflects larger plant populations, which affects the availability of solar radiation that reaches the canopy, thereby influencing the distribution of dry matter among plant organs (Resende and Costa 2005). However, since microgreens are plants in their initial growth phase, the maximum plant population did not affect SDMY gain. Instead, it allowed the interception of solar radiation crucial for photosynthesis, optimizing the allocation of dry matter (Tang and Liesche 2017).

Considering a seed density of 100 g·m^{-2}, authors obtained variation from 43.9 to 67 g·m^{-2} for SDMY of arugula microgreens cultivated during summer (Wieth et al. 2021). Using the same seed density (100 g·m^{-2}), the SDMY values observed in winter (60.2 g·m^{-2}) and spring (75.6 g·m^{-2}) in the present study resembled those findings.

Total soluble solids index

To better understand the TSS data, its values were divided by the SFMY, resulting in an index (TSS index). The index showed a linear increase result as there was an increase in seed density for microgreens cultivated in both seasons (Fig. 4a). This pattern signifies that, at higher densities, a greater concentration of soluble solids was observed. In lower seed densities, the difference between winter and spring was more pronounced, with winter showing an approximately threefold increase compared to spring.

The index analysis had mathematical adjustment for EC of nutrient solution only on winter, resulting in a linear increase (Fig. 4b). During spring, there was no adjustment, being the average 224.8.

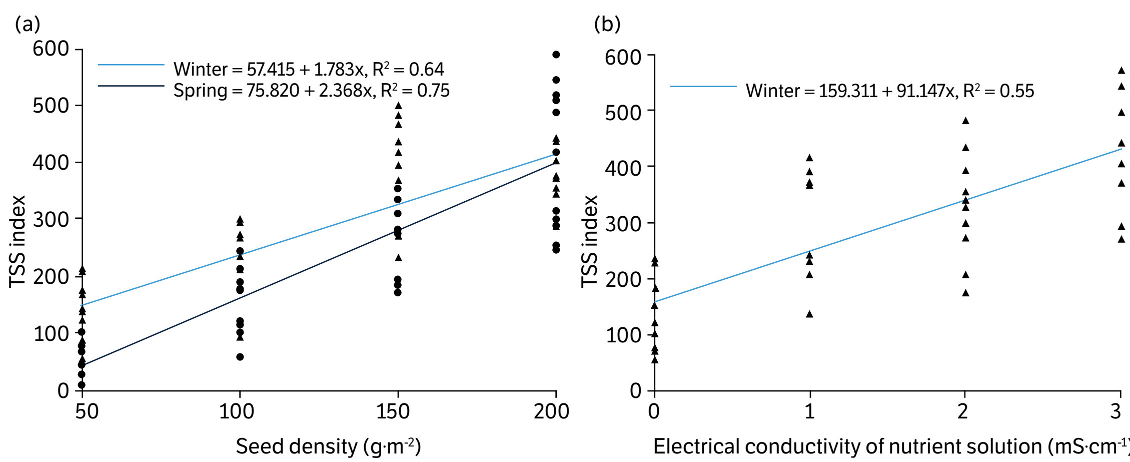

Figure 4. Arugula microgreens total soluble solids (TSS) index according to seed densities (50, 100, 150 and 200 g·m^{-2}) and electrical conductivities (0, 1, 2 and 3 mS·cm^{-1}) during (a) winter and spring and (b) winter. The observed data is represented by the points, while the trendline is the result of the equation shown in the article or in the figure. (a) TSS index in relation to seed density of arugula microgreens cultivated during winter and spring. (b) TSS index in relation to electrical conductivity of nutrient solution for arugula microgreens cultivated during winter. $p < 0.0001$. Porto Alegre, RS, Brazil, 2021.

TSS is a parameter that represents the content of sugars and acids present in plant tissue and are often related to the sweetness of products. TSS exhibited similar results to other evaluated characteristics, like SHH (except for winter), SFMY, and SDMY. Thus, the elevation of EC in the nutrient solution and seed density leads to a heightened accumulation of sugar and acids in arugula microgreens, establishing a positive correlation with food safety.

Flavor and aroma are relevant factors for microgreens consumers, and their evaluation is important since they can be influenced by the production system and management practices employed (Wieth et al. 2020), such as seed density and nutrient supply. Authors report that sensory properties are influenced by TSS, with higher TSS values promoting better aromas and flavors (Sobreira et al. 2010, Maciel et al. 2015). Therefore, knowledge of TSS values is desirable.

A study reported an average TSS value of 3.9 °Brix for beet microgreens (Santos et al. 2020). Analyzing the effect of different EC values in nutrient solution for purple cabbage microgreens, Wieth et al. (2020) observed a reduction in TSS values as there was an increase in EC, being these 5.0 °Brix (0 mS·cm^{-1}), 3.6 °Brix (1.2 mS·cm^{-1}) and 2.7 °Brix (2 mS·cm^{-1}). This result is similar to the findings of the present work, yet further research is essential to validate the relationship between TSS and sensory characteristics in microgreens.

CONCLUSION

According to the results obtained, it was possible to conclude that:

- Considering arugula microgreens cultivation, during winter, superior results were achieved by utilizing 150 $g \cdot m^{-2}$ of seeds along with a nutrient solution at an EC of 1 $mS \cdot cm^{-1}$, achieving the desired height and SFMY. However, during spring, the results indicated that it is necessary to use 175 $g \cdot m^{-2}$ of seeds and a nutrient solution with at least an EC of 1 $mS \cdot cm^{-1}$ to secure superior result, especially SHH and SFMY;
- The increase of EC in nutrient solution (winter cycle) or in seed density (winter and spring cycles) results in higher TSS accumulation in shoot fresh matter of arugula microgreens.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION

Conceptualization: Lerner, B. L. and Strassburger, A. S.; **Formal analysis:** Lerner, B. L.; **Investigation:** Lerner, B. L., Strassburger, A. S and Schafer, G.; **Methodology:** Lerner, B. L., Strassburger, A. S. and Schafer, G.; **Project administration:** Strassburger, A. S. and Schafer, G.; **Writing – review & editing:** Lerner, B. L., Strassburger, A. S. and Schafer, G

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study. Supplementary material is available on request to the corresponding author.

FUNDING

Conselho Nacional de Desenvolvimento Científico e Tecnológico
Grant No: 131892/2020-7

ACKNOWLEDGMENTS

The authors are grateful to Tatiana da Silva Duarte for providing the equipment of microgreens pool's.

REFERENCES

Bezerra, T. J., Silva, T. T., Loss, R. A., Geraldi, C. A. Q. and Guedes, S. F. (2022). Importância das condições de armazenamento de microgreens: Análise bibliométrica e revisão de literatura. Research, Society and Development, 11, e25211326584. https://doi.org/10.33448/rsd-v11i3.26584

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

Di Gioia, F. and Santamaria, P. (2015). Microgreens. Eco-logica. Bari: Universita degli Studi di Bari Aldo Moro.

Ferreira, E. G. B. S., Matos, V. P., Sales, A. G. A. and Pacheco, M. V. (2008). Influência da temperatura e do substrato na germinação e desenvolvimento inicial de plântulas de rúcula (*Eruca sativa* Mill.). Revista Brasileira de Ciências Agrárias, 3, 209-212. https://doi.org/10.5039/agraria.v3i3a234

Gerovac, J. R., Craver, J. K., Boldt, J. K. and Lopez, R. G. (2016). Light Intensity and Quality from Sole-source Light-emitting Diodes Impact Growth, Morphology, and Nutrient Content of Brassica Microgreens. HortScience, 51, 497-503. https://doi.org/10.21273/HORTSCI.51.5.497

Gonçalves-Trevisoli, E. D. V., Mendonça, H., Dildey, O. D. F., Dartora, J., Rissato, B. B., Coltro-Roncato, S. and Echer, M. M. (2017). Ambiência e desempenho produtivo de rúcula cultivada em diferentes espaçamentos. Scientia Agraria Paranaensis, 16, 230-236. https://doi.org/10.18188/1983-1471/sap.v16n1p230-236

Instituto Nacional de Meteorologia (INMET) (2022). Banco de Dados Meteorológicos. Brazil: INMET. Available at: https://portal.inmet.gov.br/. Accessed on: Mar. 3, 2022.

Kyriacou, M. C., Rouphael, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., Pascale, S. and Santamaria, P. (2016). Micro-scale vegetable production and the rise of microgreens. Trends in Food Science & Technology, 57, 103-115. https://doi.org/10.1016/j.tifs.2016.09.005

Lima, Â. A., Miranda, E. G., Campos, L. Z. O., Cuznato Junior, W. H., Mello, S. C. and Camargo, M. S. (2004). Competição das cultivares de alface Vera e Verônica em dois espaçamentos. Horticultura Brasileira, 22, 314-316. https://doi.org/10.1590/S0102-05362004000200030

Lima, J. S. S., Neto, F. B., Negreiros, M. Z., Freitas, K. K. C. and Barros Júnior, A. P. (2007). Desempenho agroeconômico de coentro em função de espaçamentos e em dois cultivos. Revista Ciência Agronômica, 38, 407-413.

Maciel, G., Fernandes, M., Hillebrand, V. and Azevedo, B. (2015). Influência da época de colheita no teor de sólidos solúveis em frutos de minitomate. Scientia Plena, 11, 120203. https://doi.org/10.14808/sci.plena.2015.120203

Murphy, C. and Pill, W. (2010). Cultural practices to speed the growth of microgreen arugula (roquette; Erica vesicaria subsp. Sativa). Journal of Horticultural Science and Biotechnology, 85, 171-176. https://doi.org/10.1080/14620316.2010.11512650

Nolan, D. A. (2019). Effects of Seed Density and Other Factors on the Yield of Microgreens Grown Hydroponically on Burlap (Report). Virginia Tech.

Palmitessa, O. D., Renna, M., Crupi, P., Lovece, A., Corbo, F. and Santamaria, P. (2020). Yield and Quality Characteristics of Brassica Microgreens as Affected by the NH4:NO3 Molar Ratio and Strength of the Nutrient Solution. Foods, 9, 677. https://doi.org/10.3390/foods9050677

Pinheiro, W. D., Wieth, A. R., Carvalho, A. C., Duarte, T. S. and Silva, M. A. S. (2021). Rúcula hidropônica sob diferentes densidades e concentrações de solução no período de outono e inverno. Brazilian Journal of Development, 7, 23206-23220. https://doi.org/10.34117/bjdv7n3-165

Resende, G. M. and Costa, N. D. (2005). Características produtivas e conservação pós-colheita de cebola em diferentes espaçamentos de plantio. Horticultura Brasileira, 23, 707-711. https://doi.org/10.1590/S0102-05362005000300003

Resh, H. M. (2012). Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower. Boca Raton: CRC Press.

Santos, F. L., Costa, E. S. and Lima, C. S. M. (2020). Diferentes substratos no desenvolvimento e na pós-colheita de microverdes de beterraba (Beta vulgaris L.). Revista Iberoamericana de Tecnología Postcosecha, 21, 2-10.

Santos, O. S. (2010). Elaboração de solução hidropônica para rúculas. Santa Maria: Editora UFSM.

Senevirathne, G., Gama-Arachchige, N. and Karunaratne, A. (2019). Germination, harvesting stage, antioxidant activity and consumer acceptance of ten microgreens. Ceylon Journal of Science, 48, 91-96. https://doi.org/10.4038/cjs.v48i1.7593

Sobreira, F., Sobreira, F., Almeida, G., Coelho, R., Rodrigues, R. and Matta, F. (2010). Taste quality of salad and cherry tomatoes and their relationship with the morphoagronomic characteristics of the fruits. Ciência e Agrotecnologia, 34, 1015-1023. https://doi.org/10.1590/S1413-70542010000400031

Sun, J., Xiao, Z., Lin, L., Lester, G. E., Wang, Q., Harnly, J. M. and Chen, P. (2013). Profiling Polyphenols in Five Brassica species Microgreens by UHPLC-PDA-ESI/HRMSn. Journal of Agricultural and Food Chemistry, 61, 10960-10970. https://doi.org/10.1021/jf401802n

Tang, Y. and Liesche, J. (2017). The molecular mechanism of shade avoidance in crops – How data from Arabidopsis can help to identify targets for increasing yield and biomass production. Journal of Integrative Agriculture, 16, 1244-1255. https://doi.org/10.1016/S2095-3119(16)61434-X

Treadwell, D. D., Hochmuth, R., Landrum, L. and Laughlin, W. (2010). Microgreens: A New Specialty Crop. EDIS.

Xiao, Z., Lester, G. E., Luo, Y. and Wang, Q. (2012). Assessment of Vitamin and Carotenoid Concentrations of Emerging Food Products: Edible Microgreens. Journal of Agricultural and Food Chemistry, 60, 7644-7651. https://doi.org/10.1021/jf300459b

Wieth, A. R., Pinheiro, W. D. and Duarte, T. D. S. (2020). Purple cabbage microgreens grown in different substrates and nutritive solution concentrations. Revista Caatinga, 32, 976-985. https://doi.org/10.1590/1983-21252019v32n414rc

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