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# Effect of different sowing densities and substrates on the growth of arugula seedlings

# Efecto de diferentes densidades de siembra y sustratos en el crecimiento de plántulas de rúcula

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**Arugula seedlings in trays.**

Photo: T.T. Fiorin (2022)


## ABSTRACT

Arugula is known for the spicy flavour of its leaves, and it is an important crop due to its high productivity and multiple harvests per year. However, seedling quality may limit its production. This study examined arugula seedling emergence and production at different sowing densities and substrate compositions. In a greenhouse, the broadleaf cultivar was randomized with a 5×3 factorial design (substrate compositions: 100% medium textured sand (SD), 100% Carolina Soil® commercial substrates (CS), 50%SD+50%CS, 75%SD+25%CS, and 25%SD+75%CS, and sowing densities: 5; 10 and 15 seeds/alveolus); with five replications. Analyzes were carried out on emergence speed index and mean emergence time, as well as on relative frequency, lengths of aerial and root parts, number of leaves, and rating scales according quality for tuft formation (or bouquets) and clod stability. All seeding densities and substrate compositions showed good seedling formation, except for the 100% SD composition, which showed low adherence in the substrate-plant-container-water system for tuft formation and clod stability. Except for 100% SD composition, an average of 70% of seedling emergence was at 9.7 d. For the production of commercial seedlings, it is indicated the use of 10 or more seeds per alveolus, and all substrate compositions tested in this study, except 100% SD.


**Additional key words:** *Eruca vesicaria* subsp. *sativa* (Miller) Thell.; formation of tufts; clod structure; seedling production.

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## RESUMEN

La rúcula es conocida por el sabor picante de sus hojas, y es un cultivo importante por su alta productividad y múltiples cosechas al año, sin embargo, la calidad de las plántulas limitan su producción. Este estudio examinó la emergencia y producción de plántulas de rúcula a diferentes densidades de siembra y composiciones de sustrato. En invernadero, el cultivar de hoja ancha se aleatorizó con un factorial 5×3 (composiciones de sustrato: 100% arena de textura media (ATM), 100% sustratos comerciales Carolina Soil® (CS), 50% SD+50 % CS, 75% SD+25% CS, y 25% SD+75% CS; y densidades de siembra de 5, 10 y 15 semillas/alvéolo) con cinco repeticiones. Se realizaron análisis sobre el índice de velocidad de emergencia y el tiempo medio de emergencia, así como sobre la frecuencia relativa, la longitud de las partes aéreas y de la raíz, el número de hojas y las escalas de calificación según la calidad para la formación de penachos (o ramilletes) y la estabilidad del terrón. Todas las densidades de siembra y composiciones de sustrato mostraron buena formación de plántulas, excepto la composición 100% ATM, que mostró baja adherencia en el sistema sustrato-planta-recipiente-agua para la formación de penachos y la estabilidad del terrón. Excepto por la composición 100% ATM, un promedio del 70% de la emergencia de las plántulas fue a los 9,7 d. Para la producción de plántulas comerciales, se indica el uso de 10 o más semillas por alvéolo y todas las composiciones de sustrato probadas en este trabajo, excepto 100% ATM.



**Palabras clave adicionales:** *Eruca vesicaria* subsp. *sativa* (Miller) Thell.; formación de mechones; estabilidad del terrón; producción de plántulas.

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## INTRODUCTION

The arugula crop (*Eruca vesicaria* subsp. *sativa* (Miller) Thell. syn. *Eruca sativa* Mill.) is one of the most consumed leafy vegetables in Latin America, it presents a characteristic spicy flavor, with several cultivation cycles in the same year and high profitability per area. Belonging to the Brassicaceae family, it is an annual and herbaceous crop, with leaves in tones of green with greenish-purplish veins and smooth or jagged edges. Its cultivation cycle is between 35 and 60 days after sowing (DAS), depending on the cultivar and the time of year, with height ranging from 15 to 25 cm (Purquerio *et al*., 2007; Santos *et al*., 2011; Filgueira, 2003).

Arugula can be produced in two ways, the first in beds with direct sowing, where the harvest is carried out by cutting the leaves, generally with 4 to 6 cuts per cycle; the second way is in the hydroponic system, where the plant is harvested whole including the root system. Although both forms of production may be highly profitable, the demand for homogeneous and quality seedlings becomes one of the limiting factors for its production (Santos *et al*., 2011; Oliveira, 2012; Sediyana *et al*., 2019).

The production of arugula seedlings in substrates should provide good structural characteristics aimed at good water retention and drainage, as the roots are sensitive to excess moisture. Due to this particularity of its roots, Fiorin *et al*. (2021) recommend the production of leafy vegetable seedlings in trays containing substrate, with irrigation using the Deep Film Technique (DFT) method, as this irrigation method occurs by capillarity and then there is the total drainage of the water, promoting aeration and porosity at the same time as the necessary humidity for the germination and formation of seedlings.

In the horticultural sector, the preparation of substrates is a common practice and must be specific for each plant species, thus enabling this species to express its germination potential and, consequently, the development of aerial and root parts. The substrate within the substrate-plant-container-water system acts as a physical input for root growth and development, at the same time it must provide aeration and porosity conditions, through the interaction of the different granulometry of the particles used in its composition, aiming at ideal capacities of water retention and drainage of the substrate in the container (Rodrigues, 2002; Kämpf *et al*., 2006; Takane *et al*., 2013; Al-Taey and Al-Musawi, 2022).

Another important factor in the production of seedlings is sowing density, for most leafy vegetable species only one seed is used per alveolus in the tray, for example, lettuce (*Lactuca sativa* L.) and cabbage or kale (*Brassica oleracea* L.). However, for plants such as arugula there is need for sowing to occur in tufts or bouquets, using more than one seed to form the commercial bunch. Nevertheless, there is a divergence in the ideal number of seeds per alveoli to form the commercial pack, there is an indication ranging from 5 to 40 seeds, in which the smaller number of units per alveoli are destined for hydroponic cultivation and larger number of units per alveoli go to the cultivation in the field, sometimes requiring thinning (Santos *et al*., 2011; Oliveira, 2012; Sediyana *et al*., 2019).

Thus, the objective of this study was to evaluate seedling emergence and the production of arugula seedlings cultivated at different sowing densities and substrate compositions.

## MATERIAL AND METHODS

The experiment was carried out from September to November 2022, in the Olericulture Sector of the Polytechnic College of the Federal University of Santa Maria (UFSM), located in Santa Maria, RS (29º43' S, 53º43' W and altitude of 95 m). The climate in the region is humid subtropical (Cfa), according to the Köppen-Geiger classification, with an average annual rainfall of 1,769 mm, average annual temperature close to 19.2ºC and air humidity around 78.4% (Alvares *et al*., 2013).

The experiment was carried out in a greenhouse, in a completely randomized design, organized in a 5×3 factorial scheme (substrate compositions and sowing densities), with five replications, each experimental unit consisting of 20 alveoli. Substrate compositions were in the proportions of 100% medium textured sand (SD), 100% Carolina Soil® commercial substrate (CS), 50% SD+50% CS, 75% SD+25% CS and 25% SD+75% CS (Tab. 1); sowing densities were 5, 10 and 15 seeds per alveolus.

Sowing was carried out in expanded polystyrene (Styrofoam™) trays with 200 alveoli (15.6 mL volume, 5 cm high, pyramid-shaped cell, with the seeds buried at 1 cm) containing the substrates and according to the number of aforementioned seeds. Irrigation was performed three times a day, lasting 30 min each session, to increase the water flow and its subsequent drainage, using the Deep Film Technique (DFT) method, on a table with only 3 cm of water, without the use of nutrient solution. Irrigation water had an electrical conductivity (EC) of 0.61 dS $m^{-1}$.

**Table 1. Substrate material properties.**

| Parameters | Medium texture sand (SD) | Commercial substrate Carolina Soil® (CS) |
|---|---|---|
| Density | 1,400 (kg $m^{-3}$) | 500 (kg $m^{-3}$) |
| Porosity | 31% | 85% |
| Aeration space | 67% | 25% |
| Water holding capacity | 10% | 39% |
| Pores/solids (P/S) ratio | 2.0 | 5.7 |

Adapted from Kämpf *et al.* (2006) and Takane *et al.* (2013).

The parameters evaluated were the counts of seedlings emerged daily, until emergence stabilization at 14 DAS, this period being used to calculate the emergence speed index (ESI) (Maguire, 1962), mean emergence time (MET; d) (Furbeck *et al*., 1993) and the relative frequency of emergence (*Fr*), expressed in Equation [$Fr = ni\ /\ \sum_{i=1}^{k}$], where, *Fr* was relative frequency of emergence, *ni* the number of seedlings emerged per day; $\Sigma ni$ = total number of emerged seedlings (Labouriau and Valadares, 1976).

At 15 DAS, it was evaluated the length (cm) of aerial and root parts, both measured with a millimeter ruler; the number of leaves (unit) by manual counting; rating scales for the quality of the seedlings according to the formation of tufts or bouquets (Fig. 1A and 1C); and stability of the seedlings in relation to the permanence of the root ball in the container (Fig. 1B).

In the formation of seedlings, the formation of tufts or bouquets was graded from 1 to 5, in which grade 1: no tuft formation, with few formed leaves, no lateral filling and up to 20% of alveolus coverage (CA); grade 2: poorly formed tuft, few erect and expanded leaves, without lateral filling and up to 40% of the CA; grade 3: tuft formed with erect and expanded leaves, without lateral filling and up to 60% of the CA; grade 4: tuft formed with erect and expanded leaves, with little lateral filling and up to 80% of the CA; grade 5: well-formed tuft with erect and expanded leaves,

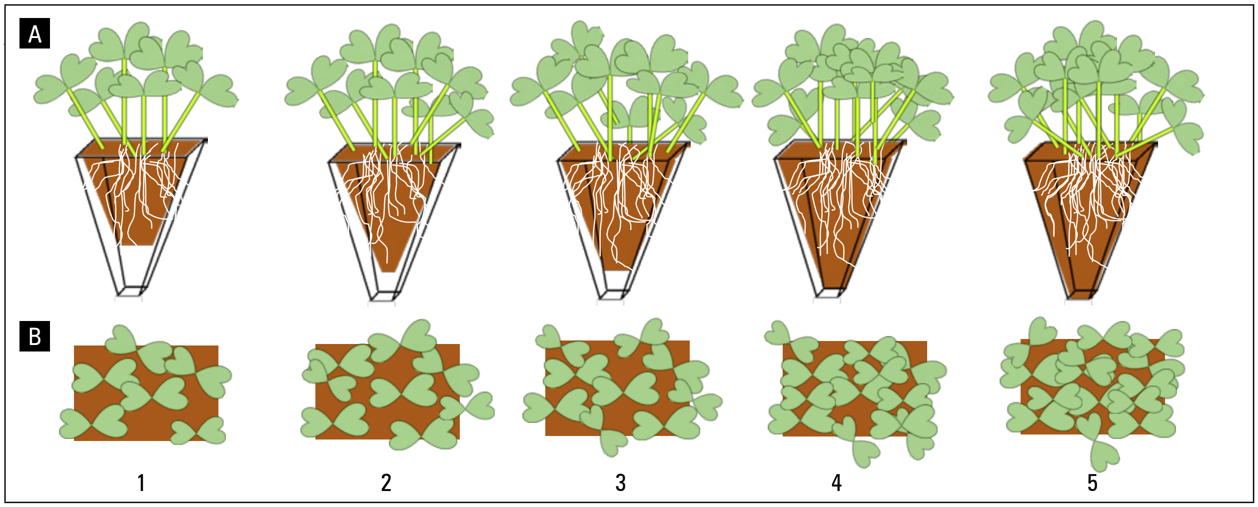


**Figure 1. Rating scales for seedling quality according to the formation of tufts or bouquets (A: side view and C: top view) and rating scale for clod structure (B) for arugula (*E. vesicaria* subsp. *sativa*). Adapted from Menegaes *et al.* (2017).**

with lateral filling and more than 90% of the CA; the other grades are intermediate in percentage (Fig. 1).

For clod stability in relation to the permanence of the clod in the container, grades 1 to 5 were assigned according to the methodology of Menegaes *et al*. (2017), in which grade 1: low stability, above 50% of the clod is retained in the container, and the clod does not remain cohesive; grade 2: between 10 and 30% of the clod is retained in the container, and the clod does not remain cohesive; grade 3: the clod separates from the container, but it does not remain cohesive; grade 4: the clod detaches itself from the container, but there is a loss of up to 10% of the substrate; grade 5: all the clod is detached from the container and more than 90% of it remains cohesive (Fig. 1).

Data expressed in percentages were transformed into arcsine and analysis of variance (ANOVA) and comparison of means using the Scott-Knott test ($P<0.05$) with the aid of the SISVAR statistical program (Ferreira, 2014).

## RESULTS AND DISCUSSION

In Tab. 2, it was observed that there was a significant interaction between substrate compositions and arugula sowing densities, in which the germinations were above 70% for all compositions of substrates and sowing densities tested, except for the composition of 100% medium textured sand (SD) for all sowing densities. This confirms the minimum quality required by Ordinance nº. 111/2012 of the Ministry of Agriculture, Livestock and Supply (Brasil MAPA, 2012), for a batch of horticultural seeds to be commercial.

It was found that seedling emergence at 14 DAS resulted in averages of 81, 83 and 78% for seeding densities containing 5; 10 and 15 units per alveolus and averages of 60, 82, 89, 86 and 85% for substrate compositions of 100% SD, 100% CS, 50% SD+50% CS, 75% SD +25% CS and 25% SD+75% CS, respectively.

These data corroborate the work by Fiorin *et al*. (2022), who evaluated the emergence of broccoli (*B. oleracea* L. var. *italica*) and cauliflower (*B. oleracea* L. var. *botrytis*), respectively, in different substrate compositions, in trays using irrigation by the DFT method, in which the average percentages of emergence were more than 70%, thus indicating good conditions for the production of seedlings of these species. The same authors also verified that the use of 100% sand as substrate composition resulted in a low seedling emergence for both species.

It was observed that the general means of the emergence speed indexes (ESI) were 54.352; 55.164 and 60.527 for seeding densities containing 5; 10 and 15 seeds per alveolus, respectively. Among the substrate compositions, 75% SD+25% CS and 25% SD+75% CS stand out, both compositions containing 15 seeds per alveolus, with averages of 68.839 and 67.349, respectively.

**Table 2. Emergence speed index (ESI) and mean emergence time (MET) of arugula (*E. vesicaria* subsp. *sativa*) grown in different sowing densities and substrates.**

| Substrate compositions | Sowing density (seeds per alveolus) | | |
|---|---|---|---|
| | 5 | 10 | 15 |
| Emergency (%) | | | |
| 100% SD | 56 Bd | 63 Ac | 62 Ac |
| 100% CS | 80 Bc | 83 Ab | 83 Ab |
| 50% SD +50% CS | 90 Aa | 89 Aa | 87 Ba |
| 75% SD +25% CS | 90 Aa | 90 Aa | 78 Bc |
| 25% SD +75% CS | 88 Ab | 89 Aa | 79 Bc |
| CV (%) | 3.56 | | |
| Speed index (ESI) | | | |
| 100% SD | 47.580 Cd | 54.634 Ab | 51.333 Bd |
| 100% CS | 50.090 Bc | 54.803 Ab | 54.803 Ac |
| 50% SD +50% CS | 59.790 Aa | 56.722 Ba | 60.311 Ab |
| 75% SD +25% CS | 56.376 Bb | 53.570 Cc | 68.839 Aa |
| 25% SD +75% CS | 57.922 Bb | 56.089 Ca | 67.349 Aa |
| CV (%) | 7.11 | | |
| Mean emergence time (d) | | | |
| 100% SD | 10.0 Aa | 10.1 Aa | 9.9 Ba |
| 100% CS | 9.6 Bb | 9.8 Ab | 9.8 Aa |
| 50% AR +50% CS | 9.4 Bc | 9.5 Bc | 9.6 Ab |
| 75% AR +25% CS | 9.6 Bb | 9.8 Ab | 9.8 Aa |
| 25% AR +75% CS | 9.4 Cc | 9.6 Bc | 9.8 Aa |
| CV (%) | 2.94 | | |

CS: Carolina Soil® commercial substrate and SD: medium textured sand.

Significant interaction of factors, test of means not followed by the same letter, uppercase in the line and lowercase in the column, differ by the Scott-Knott test ($P<0.05$). CV: Coefficient of variation.

The general average of mean emergence time (MET) was 9.7 d in all substrate compositions and seeding densities. Oliveira (2012) mentions that the emergence for the production of arugula seedlings in hydroponic cultivation varies from 5 to 9 DAS, depending on the time of year and the region of cultivation.

It was observed that the composition of 100% SD obtained an average of 10 d. According to Kämpf *et al*. (2006), this can be attributed to the structure and granulometry of the sand, which has high density, drainage and aeration and low water retention capacity. For Takane *et al*. (2013) and Fiorin *et al*. (2022), the interactions between the materials used for the elaboration of the substrates, the container and the irrigation method are desirable to favor root growth and development, resulting in the full growth and development of the aerial part, which did not occur in the 100% SD composition for all sowing densities.

The ESI and MET parameters for arugula seedling emergence, under the aforementioned experimental conditions, can be confirmed in Fig. 2, in which the percentages of relative frequencies (Fr) of emerged seedlings indicate similarity of emergence peaks for sowing densities containing 5; 10 and 15 seeds per alveolus, which on average reach MET of 9.7 d overall. However, the ESI from the 1st to the 14th DAS occurred heterogeneously, which can be attributed to the interaction of the substrate composition, in particular due to its structure and different size particles.

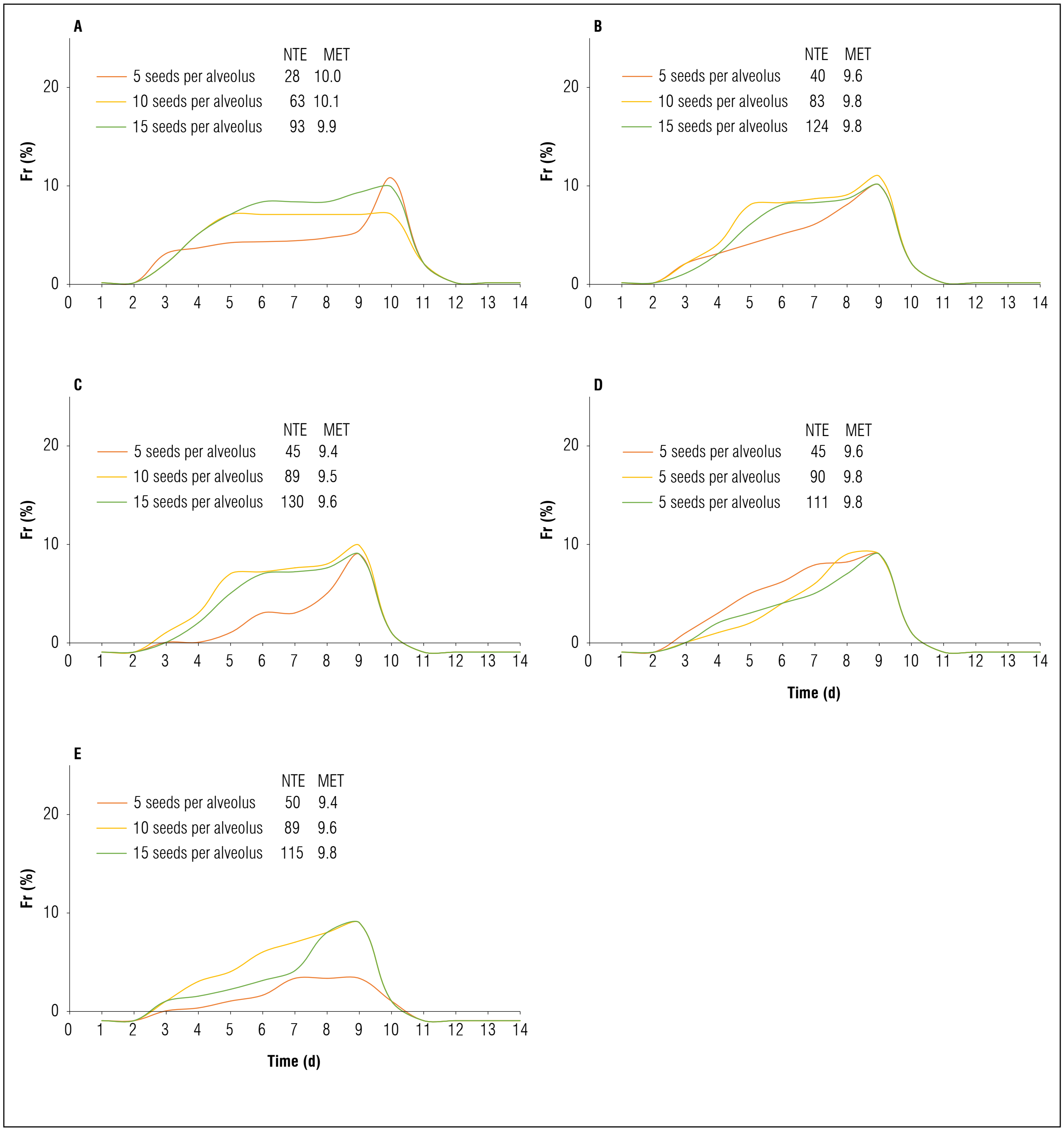


**Figure 2. Relative frequencies (Fr; %) of arugula (*E. vesicaria* subsp. *sativa*) emerged seedlings cultivated in different sowing densities and substrates: A, 100% SD; B, 100% CS; C, 50% AR +50% CS; D, 75% AR +25% CS; E, 25% AR +75% CS. CS: Carolina Soil® commercial substrate and SD: medium textured sand. NTE: number of emerged seedlings (units per repetition). MET: mean emergence time (d).**

The synchronization of emergence peaks, according to Nassif and Perez (2000) and Menegaes *et al*. (2020), is also an indication of the organization of the seed membrane system associated with its physiological quality (vigor), with a positive impact on the production of homogeneous and commercial seedlings.

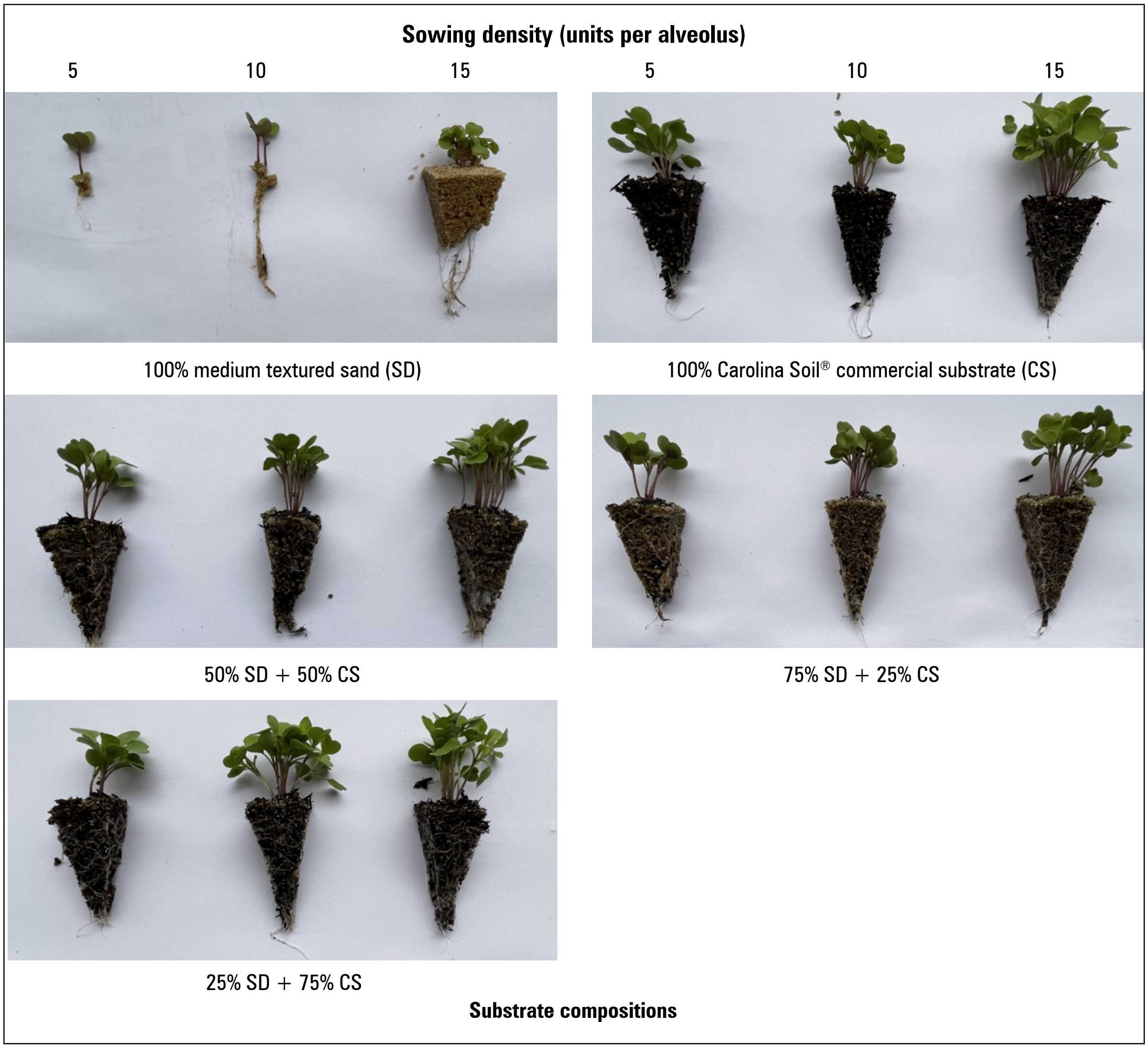


**Figure 3. Seedlings of arugula (*E. vesicaria* subsp. *sativa*) cultivated in different sowing densities and substrates, in trays using the DFT irrigation method: A, 100% SD; B, 100% CS; C, 50% AR +50% CS; D, 75% AR +25% CS; E, 25% AR +75% CS. CS: Carolina Soil® commercial substrate and SD: medium textured sand.**

A good development of arugula seedlings was verified at 15 DAS due to the interactions in the substrate-plant-container-water system for all sowing densities in the different substrate compositions, except in the 100% SD composition (Fig. 3 and Tab. 3).

According to Menegaes *et al*. (2017), the harmony of this system is the result of its interaction, providing the stability for clod formation, with the adhesion of the root system after its removal from the container, favoring the quality of the seedlings and the success of their “setting” in the field or in hydroponic cultivation after transplanting.

The lengths of aerial and root parts indicate good vigor (physiological quality) of the seeds to form well-developed seedlings for later transplanting. Average lengths for all substrate compositions were 2.6; 2.7 and 2.8 cm for root and 3.8; 4.4 and 4.3 cm for the shoots part, in the respective sowing densities containing 5; 10 and 15 units per alveolus (Tab. 3). It was found that the average number of leaves and

**Table 3.** **Lengths of aerial and root parts, number of leaves, dry mass of seedlings, formation of the tuft or bouquet and stability of the arugula clod (*E. vesicaria* subsp. *sativa*) cultivated in different sowing densities and substrates.**

| Substrate compositions | Sowing density (seeds per alveolus) | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 5 | 10 | 15 |
| | Lengths of root part (cm) | | | Lengths of aerial part (cm) | | |
| 100% SD | 0.9 Be | 1.0 Ae | 1.1 Ad | 3.0 Ac | 2.5 Bc | 3.1 Ac |
| 100% CS | 2.7 Cc | 3.3 Ab | 3.5 Aa | 3.5 Bb | 4.8 Ab | 4.5 Ab |
| 50% SD +50% CS | 3.1 Ab | 3.0 Ac | 3.2 Ab | 4.8 Ba | 4.7 Bb | 5.0 Aa |
| 75% SD+25% CS | 2.3 Bd | 2.4 Bd | 3.0 Ac | 3.5 Cb | 5.3 Aa | 4.7 Ba |
| 25% SD +75% CS | 3.8 Aa | 3.7 Aa | 3.5 Ba | 4.4 Ba | 4.9 Ab | 4.0 Cb |
| CV (%) | 4.17 | | | 3.71 | | |
| | **Number of leaves (unit/plant)** | | | **Dry mass of seedlings (mg/plant)** | | |
| 100% SD | 2.0 Bd | 2.6 Ac | 2.8 Ac | 0.03 Ad | 0.02 Ad | 0.07 Ac |
| 100% CS | 2.6 Bc | 3.2Ab | 3.6 Ab | 0.20 Ac | 0.12 Bc | 0.11 Bb |
| 50% SD +50% CS | 3.2 Bb | 4.2 Aa | 4.0 Aa | 0.24 Ac | 0.19 Bb | 0.21 Aa |
| 75% SD+25% CS | 3.8 Ba | 4.0 Aa | 4.2 Aa | 0.45 Aa | 0.32 Ba | 0.26 Ca |
| 25% SD +75% CS | 3.8 Ba | 4.2 Aa | 4.0 Aa | 0.31 Ab | 0.22 Bb | 0.14 Cb |
| CV (%) | 4.51 | | | 5.59 | | |
| | Formation of the tuft (grade) | | | Clod stability (grade) | | |
| 100% SD | 1.3 Bc | 1.4 Bc | 1.8 Ac | 1.5 Bb | 1.9 Bc | 2.6 Ac |
| 100% CS | 4.7 Ba | 4.9 Aa | 4.9 Aa | 4.1 Aa | 4.1 Ab | 4.0 Ab |
| 50% SD +50% CS | 4.6 Ba | 4.8 Aa | 4.8 Aa | 4.2 Aa | 4.0 Ab | 4.3 Aa |
| 75% SD+25% CS | 4.2 Bb | 4.5 Bb | 4.9 Aa | 4.1 Aa | 4.2 Ab | 4.2 Ab |
| 25% SD +75% CS | 4.6 Ba | 4.9 Aa | 4.6 Bb | 4.2 Ba | 4.6 Aa | 4.4 Aa |
| CV (%) | 3.08 | | | 3.75 | | |

CS: Carolina Soil® commercial substrate and SD: medium textured sand.

Significant interaction of factors, test of means not followed by the same letter, uppercase in the line and lowercase in the column, differ by the Scott-Knott test ($P<0.05$). CV: Coefficient of variation.

dry mass of arugula seedlings for all sowing densities were 2.5 3.1; 3.8; 4.0 and 4.0 units/plant and 0.04; 0.15; 0.22; 0.34 and 0.22 mg/plant for substrate compositions of 100% SD, 100% CS, 50% SD+50% CS, S4: 75% SD+25% CS and 25% SD+75% CS, respectively. It was observed once again that the substrate composition with 100% SD resulted in small and poorly formed seedlings (Fig. 3).

For Santos *et al*. (2011) and Sediyana *et al*. (2019), the success of arugula leaf cultivation lies in the production of well-formed seedlings. These authors indicate that the transplantation of seedlings, both for hydroponic cultivation and for cultivation in beds in the soil, must have a well-formed and cohesive root system in the substrate, the aerial part between 2 to 3 cm, with the primary leaves erect and expanded. In this study, only the substrate composition containing 100% SD did not comply with the indications by the aforementioned authors.

It was observed that there was an excellent formation of the tuft or bouquet, as well as stability for the formation of the clod with the adherence of the root system of arugula seedlings, cultivated in different sowing densities and substrates, indicating that all substrate compositions, except 100% SD, provide good conditions for the formation of seedlings in the substrate-plant-container-water system.

The formation of the root system predicted in Fig. 1 for the establishment of grades was confirmed in Fig. 3, and with the results in Tab. 3, all with grades equal to or greater than 4.0 for both parameters of tuft formation and stability of clod formation with the adhesion of the root system of arugula seedlings. It should be noted that the larger and better-formed shoots, the greater the homogeneity and commercial value of the seedlings. In this context, sowing densities with 10 or more seeds per alveolus favored the formation of the best evaluated shoots.

The arugula seedlings formed by a very cohesive and harmonious tuft indicate development of the aerial part with erect and expanded leaves, as well as the formation of the clod with adherence of the root system which, when it is totally detached from the container, remains intact. According to Menegaes *et al*. (2017), for there to be interaction in the substrate-plant-container-water system, the stability of the root ball must be formed and cohesive, remaining aggregated after being removed from the container, without damage to the root system, thus facilitating transplantation, in which the higher the score, the better is the quality of the seedling.

## CONCLUSION

There was good emergence of arugula seedlings at different sowing densities and substrate compositions, with averages above 70% and average emergence time of 9.7 d, except for the 100% SD substrate composition. For the formation of homogeneous and commercial seedlings, it is indicated the use of 10 or more seeds per alveolus. All substrate compositions tested in this study, except the composition of 100% SD, demonstrated low adherence and structure from the emergence to the formation of seedlings.

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