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ROCK POWDER AS A TOOL IN THE PRODUCTION OF ARUGULA SEEDLINGS IN SUBSTRATES

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ABSTRACT - The interaction between rock powder and substrates in arugula and the amount to be used of this remineralizer are not elucidated. Thus, the objective of the study was to investigate whether substrates associated with rock powder interfere with the phytometric morphology of seedlings and to understand the effect of remineralizer proportions, added to commercial substrate, on the development of arugula seedlings. We performed two experiments. In experiment I, the treatments were three substrates in the absence and presence of rock powder (30% of the container volume), designed in randomized blocks, with three replications. In experiment II, the treatments were six rock powder proportions (0%, 5%, 10%, 15%, 20% and 25% of the container volume), designed in randomized blocks, with three replications. In experiment I, the seedlings produced in the substrate Horta 2® had better phytometric quality. In experiment II, shoot fresh mass and seedling root volume increased until the addition of 15% rock powder to the Horta 2® substrate and decreased with proportions of 20% and 25%. There is no interactive effect between substrates and rock powder in the production of arugula seedlings in containers. Substrates with greater water retention enhance the quality of arugula seedlings because they improve their phytometric morphology. Proportions of rock powder added to the Horta 2® substrate interfere with the shoot and root system morphology of the seedlings. The increase in the proportion of this remineralizer up to 15% of the container volume, added to the growth medium, improves the aerial biomass and the root volume of arugula seedlings, 'Donatella' cultivar.
Keywords: *Eruca sativa* Miller, growth medium, remineralizer, morphology.

PÓ-DE-ROCHA COMO FERRAMENTA NA PRODUÇÃO DE MUDAS DE RÚCULA EM SUBSTRATOS

RESUMO - A interação entre pó-de-rocha e substratos em rúcula e a quantidade a ser usada desse remineralizador não estão elucidadas. Assim, o objetivo do estudo foi investigar se substratos associados ao pó-de-rocha interferem na morfologia fitométrica de mudas e compreender o efeito de proporções do remineralizador, adicionadas em substrato comercial, quanto ao desenvolvimento de mudas de rúcula. Foram realizamos dois experimentos. No experimento I os tratamentos foram três substratos na ausência e presença de pó-de-rocha (30% do volume do recipiente), delineados em blocos casualizados, com três repetições. No experimento II os tratamentos foram seis proporções de pó-de-rocha (0%, 5%, 10%, 15%, 20% e 25% do volume do recipiente), delineados em blocos casualizados, com três repetições. No experimento I as mudas produzidas no substrato Horta 2® tiveram melhor qualidade fitométrica. No experimento II a massa fresca da parte aérea e o volume radicial das mudas aumentaram até a adição de 15% de pó-de-rocha ao substrato Horta 2® e decresceram com proporções de 20% e 25%. Não há efeito interativo entre substratos e pó-de-rocha na produção de mudas de rúcula em recipientes. Porém, substratos com maior retenção de água potencializam a qualidade de mudas de rúcula porque melhoram sua morfologia fitométrica. Em adição, proporções de pó-de-rocha adicionadas no substrato Horta 2® interferem na morfologia da parte aérea e do sistema radicial das mudas. O aumento da proporção deste remineralizador até 15% do volume do recipiente, adicionada ao meio de crescimento, melhora a biomassa aérea e o volume radicial de mudas de rúcula, cultivar Donatella.
Palavras-chave: *Eruca sativa* Miller, meio de crescimento, remineralizador, morfologia.

INTRODUCTION

In recent decades, interest in foods rich in biomolecules has increased because they have high antioxidant activity and act in the scavenging of free radicals (CUELLAR et al., 2021). These biomolecules can induce the expression of genes that encode metabolic enzymes with the potential to minimize the risk of several diseases, including cancer and immune dysfunctions (PASINI et al., 2012). Among these foods is arugula (*Eruca sativa* Miller), a leafy plant that produces health-beneficial compounds such as carotenoids and flavonoids (LEE et al., 2020).

This vegetable crop is a fast-growing annual species, characterized by light green leaves with a unique spicy flavor (ACEMI, 2022). Due to its short biological cycle (30-60 days) (BELL et al., 2015), arugula has growing

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economic potential. To ensure this rising production of arugula, quality seedlings must be provided to producers. Thus, the production of seedlings is one of the most important steps in the leafy vegetable's cultivation, as this process reflects on plants productive performance (CHIOMENTO et al., 2019). However, a difficulty in the production of quality seedlings in containers is to ensure the production of aerial biomass with a limited portion of roots (LEMAIRE, 1995), restricted to a small volume of substrate (CHIOMENTO et al., 2020).

Substrates used in the production of vegetable seedlings often have inconsistent physical properties because their components are derived from various sources (LISHTVAN et al., 2017). Therefore, choosing a suitable material is essential for plant development and this can minimize the negative effects of ecophysiological stresses during seedling production and after transplanting (CHIOMENTO et al., 2021a). A suitable substrate must provide sufficient water and nutrients to the plants and allow oxygen to be acquired by the roots (MENG et al., 2018). Also, due to the acquisition costs of the commercial substrate, it is possible, after its technical efficiency has been proven, to use local resources as substrate conditioners, such as rock powder. However, the use of rock powder is an unknown tool for most nurseries.

The adoption of rock powder by farmers is facilitated by the simplicity of its premises, the results obtained in terms of productivity and low costs, since there is a large availability of rocks suitable for this use (RAMOS et al., 2022). As conventional agriculture demands the large-scale use of chemical fertilizers to provide adequate conditions for plant growth (KORCHAGIN et al., 2019), the possibility of reducing the use of these inputs is one of the main factors that justifies the application of the rock powder as a remineralizer of growth media (RAMOS et al., 2015).

Unlike most formulated fertilizers, rock powder has slower solubility, providing nutrients for a longer period than conventional inputs (TELES et al., 2020). This remineralizer promotes an increase in cation exchange capacity, provides macro and micronutrients not available in soluble chemical fertilizers and acts in the correction and conditioning of the growth medium (RAMOS et al., 2022). Despite the benefits of rock powder to plants, no research has been conducted to understand the interaction between this remineralizer and growing substrates and to determine the amount of rock powder added to the growth medium in the production of arugula seedlings.

Therefore, the objective of this work was to investigate whether substrates associated with rock powder interfere in the phytometric morphology of seedlings and to understand the effect of remineralizer proportions, added in commercial substrate, in relation to the development of arugula seedlings.

MATERIAL AND METHODS

The arugula seeds used in the research were from the 'Donatella' cultivar, dark green, with smooth and wide leaves and a height of 14 to 18 cm. In this study we carried out two experiments (experiment I: addition of rock powder in substrates; experiment II: proportions of rock powder in the cultivation substrate). Both experiments were carried out in the municipality of Passo Fundo (28º 15' 46" S, 52º 24' 24" W), Rio Grande do Sul (RS), Brazil, in a greenhouse. Experiment I was conducted from February (summer) to April (autumn) 2021 and experiment II was carried out from February (summer) to March (autumn) 2022.

In experiment I, the treatments, designed in a two-factor scheme, were three substrates [charred rice husk (CRH), Horta 2® (HOR) and TN Gold® (TNG)] in the absence and presence of rock powder (30% of the container volume), arranged in a randomized block design, with three replications. Each plot consisted of ten plants. The rice husk used in the work was carbonized (KÄMPF et al., 2006). The composition of HOR consists of pine bark, vermiculite, acidity corrector and fertilizers, in amounts not supplied by the manufacturer. The TNG composition consists of sphagnum peat, expanded vermiculite, dolomitic limestone, agricultural gypsum and fertilizers, in amounts not provided by the manufacturer. The rock powder, supplied by the company Mineração Rincão Frente, was obtained through a grinding process and then passed through vibrating sieves.

In experiment II, the treatments were six proportions of rock powder (0%, 5%, 10%, 15%, 20% and 25% of the container volume), arranged in a randomized block design, with three replications. Each plot consisted of ten plants. The rock powder used was from the same batch as the one used in experiment I. The seedlings production was carried out in expanded polystyrene trays, measuring 0.34 m wide and 0.68 m long. Each tray had 128 cells, with a volume of 35 cm^3. In experiment I, in February 2021, the trays were filled with the substrates CRH, HOR and TNG in the absence and presence (30% of the container volume) of rock powder and, after that, three arugula seeds were sown in each cell. After germination, thinning was performed, leaving one plant per cell in each tray.

The trays were kept on metal benches, 1.2 m above the soil surface, in a greenhouse (90 m^2) with a semicircular roof, installed in the northeast-southeast direction. The galvanized steel structure was covered with a low-density polyethylene film (150 µs thickness), with anti-ultraviolet additive, and the sides were covered with an anti-aphid screen. The irrigation used was with sprinklers, in the mechanized system, with a flow of 2 L min^{-1} per unit. The irrigation regime consisted of activating the sprinklers four times a day, with total wetness of seven minutes. The water depth supplied to the seedlings was 4.35 mm day^{-1}. A 200 mL sample of rock powder was analyzed to determine its chemical characterization, according to Brasil (2014) (Table 1).

TABLE 1 - Chemical characterization of rock powder.

Substances	Formula	Concentration (%)
Silicon dioxide	SiO_2	46.52
Aluminum oxide	Al_2O_3	31.63
Iron (III) oxide	Fe_2O_3	16.79
Sodium oxide	Na_2O	2.10
Magnesium oxide	MgO	1.60
Manganese monoxide	MnO	0.44
Zinc oxide	ZnO	0.29
Potassium oxide	K_2O	0.23
Titanium dioxid	TiO_2	0.17
Calcium oxide	CaO	0.17

A 500 mL sample of each substrate, in the absence and presence of rock powder, was collected and analyzed to obtain its physical attributes (Table 2), according to Brasil (2007). From these data we obtained the water retention curve of the growth media studied (Figure 1). The HOR substrate showed greater water retention and the CRH substrate had greater water drainage.

TABLE 2 - Physical properties of the substrates used in the study.

Substrates[1]	D[2]	TP	AS	RAW	BW
	(kg m^{-3})	(m^3 m^{-3})			
CRH	170.00	0.879	0.365	0.395	0.009
HOR	241.00	0.837	0.303	0.149	0.020
TNG	88.00	0.916	0.519	0.202	0.007
CRH+30RP	565.00	0.768	0.250	0.324	0.021
HOR+30RP	613.00	0.756	0.157	0.195	0.044
TNG+30RP	463.00	0.822	0.162	0.277	0.079
100RP	1,626.00	0.475	0.118	0.070	0.071

[1]CRH: carbonized rice husk; HOR: Horta 2®; TNG: TN Gold®; CRH+30RP: 70% of carbonized rice husk + 30% of rock powder; HOR+30RP: 70% of Horta 2® + 30% of rock powder; TNG+30RP: 70% of TN Gold® + 30% of rock powder; 100RP: only rock powder. [2]D: density; TP: total porosity; AS: aeration space; RAW: readily available water; BW: buffer water.

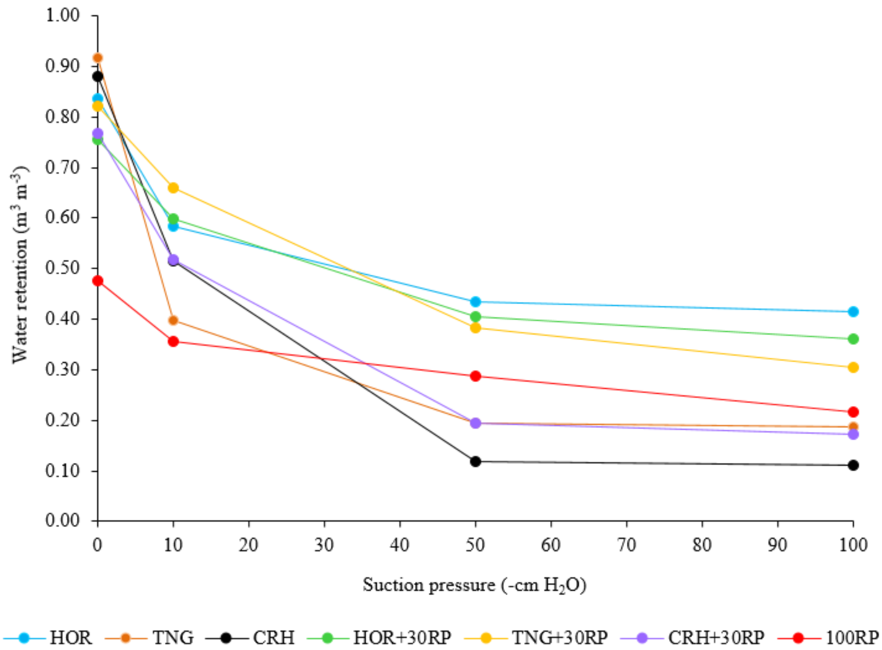

FIGURE 1 - Substrate water retention curve. HOR: Horta 2®, TNG: TN Gold®, CRH: carbonized rice husk, HOR+30RP: 70% of Horta 2® + 30% of rock powder, TNG+30RP: 70% of TN Gold® + 30% of rock powder, CRH+30RP: 70% of carbonized rice husk + 30% of rock powder, 100RP: only rock powder.

In experiment II, in February 2022, the trays were filled with treatments referring to the proportions of rock powder mixed with the substrate that had the best performance during seedling production in experiment I (see results section). Afterwards, three arugula seeds were sown in each cell. To produce the seedlings of experiment II, the same management procedures and cultural practices already mentioned during the conduction of experiment I were adopted. In both experiments were evaluated attributes of shoot morphology and root system of seedlings.

Approximately 40 days after sowing, the stem base diameter (SBD, cm) and the height of the aerial part of the seedlings (SH, cm) were measured using a digital caliper. The shoot fresh mass (SFM, g) was also evaluated.

To evaluate the morphology of the root system, the seedlings roots were collected and washed in water to eliminate the substrate fragments. The roots were digitized by a scanner and the images obtained were analyzed by the WinRHIZO® software. The attributes evaluated were total root length (TL, cm), surface area (SA, cm^2) and root volume (RV, cm^3). The roots were grouped by the software into different diameter classes in relation to their total length (BÖHM, 1979): very fine roots (VFR, Ø < 0.5 mm), fine roots (FR, Ø from 0.5 to 2.0 mm) and thick roots. (TR, Ø > 2.0 mm). The fresh mass (RFM, g) of the root system was also evaluated.

In experiment I, the data obtained were submitted to analysis of variance (ANOVA) and the means of the treatments were compared by the Tukey test, at 5% error probability. In experiment II, the data obtained were submitted to regression analysis. All analyzes were performed using the Costat® software (CoHort Software, 2003).

RESULTS AND DISCUSSION

Regarding experiment I, we did not observe a significant effect of rock powder or the interaction between rock powder and substrates regarding the seedlings phytometric morphology. However, seedlings produced on the HOR substrate presented SH, SBD and SFM higher by 70%, 49% and 67%, respectively, in relation to seedlings produced on the other substrates (Table 3). Also, seedlings produced in HOR presented TL, SA, VTR, FR and TR higher by 85%, 84%, 88%, 82% and 95%, respectively, compared to seedlings produced in TNG and CRH substrates (Table 4).

TABLE 3 - Effect of substrates on shoot morphology of arugula seedlings.

Substrates[1]	SBD[2] (cm)	SH (cm)	SFM (g)
HOR	0.15±0.004 a*	4.89±0.06 a	0.24±0.007 a
TNG	0.07±0.001 b	2.55±0.02 b	0.11±0.004 b
CRH	0.02±0.001 c	2.45±0.02 b	0.05±0.001 c
Mean	0.081	3.30	0.13
CV[3] (%)	18.10	10.32	10.68

*Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$). [1]HOR: Horta 2®, TNG: TN Gold®, CRH: carbonized rice husk. [2]SH: shoot height, SBD: stem base diameter, SFM: shoot fresh mass. [3]Coefficient of variation.

TABLE 4 - Effect of substrates on root system morphology of arugula seedlings.

Substrates[1]	TL[2] (g)	SA (cm)	VTR (cm^2)	FR (cm)	TR (cm)
HOR	220.7±93.48 a*	21.4±10.98 a	242.4±97.87 a	29.7±11.08 a	0.56±0.007 a
TNG	34.42±16.07 b	3.56±00.89 b	29.48±10.14 b	5.98±01.12 b	0.05±0.001 b
CRH	32.74±15.78 b	3.23±00.78 b	26.68±10.03 b	4.86±00.99 b	0.01±0.001 b
Mean	95.96	9.41	99.54	13.52	0.21
CV[3] (%)	10.58	10.61	13.03	13.48	14.07

*Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by the Tukey test ($p \leq 0.05$). [1]HOR: Horta 2®, TNG: TN Gold®, CRH: carbonized rice husk. [2]TL: total root length, SA: root surface area, VTR: very thin roots, FR: fine roots, TR: thick roots. [3]Coefficient of variation.

The higher quality of seedlings produced in HOR was attributed to the greater availability of water of this material, as the water retention capacity of the substrates influences the growth and development of seedlings (CHIOMENTO et al., 2019), covering shoot and root system morphology (CHIOMENTO et al., 2020). In practice, data on phytometric morphology indicated that arugula seedlings produced in the HOR substrate are more robust against biotic and/or abiotic stresses and have a more structured clod, which improves seedling support after transplanting and increases plants survival. As in CRH there is a predominance of large granulometric fractions, this impairs the water retention by the material (ZORZETO et al., 2014), which explained the inferior quality of the seedlings produced in this substrate.

In arugula cultivation, the first practice to be observed is the formation of quality seedlings. Thus, it is essential to choose substrates with physical and chemical characteristics that favor the full development of shoots and roots due to water retention, good aeration, high availability of nutrients, absence of phytopathogens, low cost and long durability (CHIOMENTO et al., 2021a).

From the results of experiment I, we selected the substrate Horta 2® (HOR) to conduct experiment II. Thus, using a 500 mL sample of HOR containing the treatments related to rock powder, we analyzed its physical attributes

(Table 5) and obtained the water retention curve of the growth media studied (Figure 2). The addition of rock powder proportions to the Horta 2® substrate increased the water retention of these mixtures.

TABLE 5 - Physical properties of the growth media used in the study.

Substrates[1]	D[2]	TP	AS	RAW	BW
	($kg\ m^{-3}$)	($m^3\ m^{-3}$)			
0% RP	255.00	0.748	0.165	0.250	0.032
5% RP	298.00	0.743	0.056	0.255	0.041
10% RP	348.00	0.751	0.088	0.222	0.039
15% RP	431.00	0.758	0.140	0.152	0.035
20% RP	449.00	0.729	0.136	0.130	0.045
25% RP	568.00	0.711	0.135	0.084	0.042
100% RP	1,626.00	0.475	0.118	0.070	0.071

[1]0% RP: only Horta 2®, 5% RP: 5% of rock powder and 95% of Horta 2®, 10% RP: 10% of rock powder and 90% of Horta 2®, 15% RP: 15% of rock powder and 85% of Horta 2®, 20% RP: 20% of rock powder and 80% of Horta 2®, 25% RP: 25% of rock powder and 75% of Horta 2®, 100% RP: only rock powder. [2]D: density, TP: total porosity, AS: aeration space, RAW: readily available water, BW: buffer water.

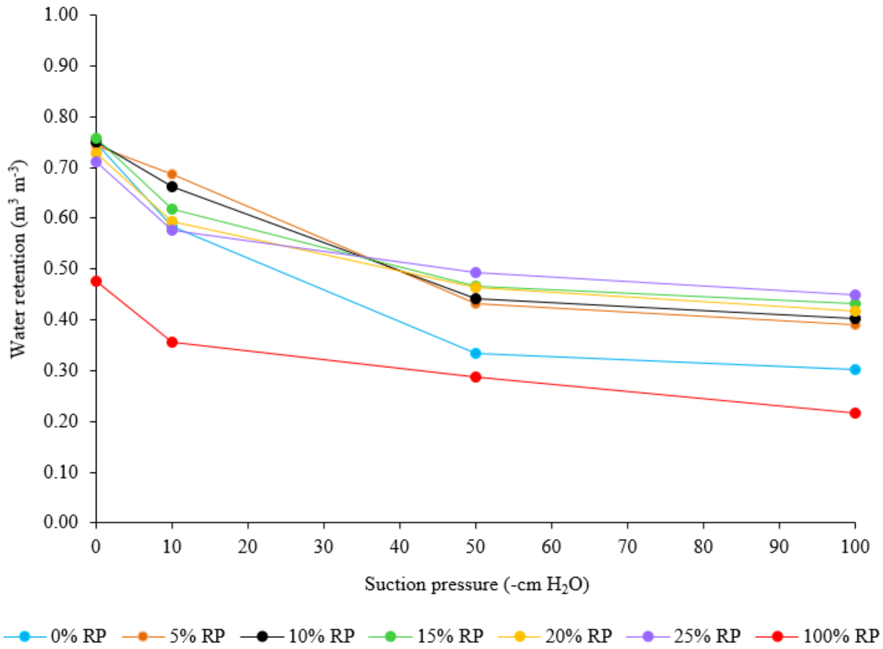

FIGURE 2 - Water retention curve of the materials studied. 0% RP: only Horta 2®, 5% RP: 5% of rock powder and 95% of Horta 2®, 10% RP: 10% of rock powder and 90% of Horta 2®, 15% RP: 15% of rock powder and 85% of Horta 2®, 20% RP: 20% of rock powder and 80% of Horta 2®, 25% RP: 25% of rock powder and 75% of Horta 2®, 100% RP: only rock powder.

As for the seedlings phytometric morphology in experiment II, the regression analysis of variance showed statistical differences for the second order polynomial regression model for the SFM and RV attributes. Regarding shoot morphology, the coefficient of determination (R^2) obtained was 0.95, indicating that SFM was explained in 95% by the proportions of rock powder (Figure 3). Furthermore, it was observed that SFM increased until the addition of 15% of rock powder to the commercial substrate Horta 2® and decreased with proportions of 20% and 25% of the remineralizer.

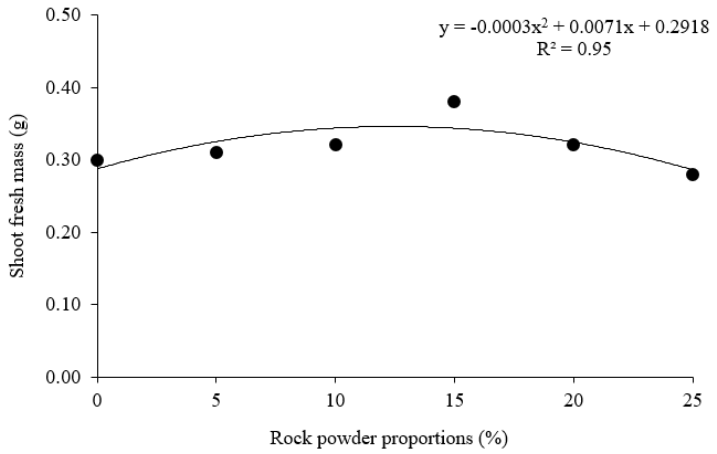

FIGURE 3 - Shoot fresh mass (SFM) of arugula seedlings as a function of rock powder proportions added to the cultivation substrate.

When analyzing the morphology of the root system, the R^2 obtained was 0.93, indicating that the RV was explained in 93% by the proportions of rock powder (Figure 4). In addition, we showed that the RV increased until the addition of 15% of rock powder to the commercial substrate Horta 2® and decreased with proportions of 20% and 25% of the remineralizer.

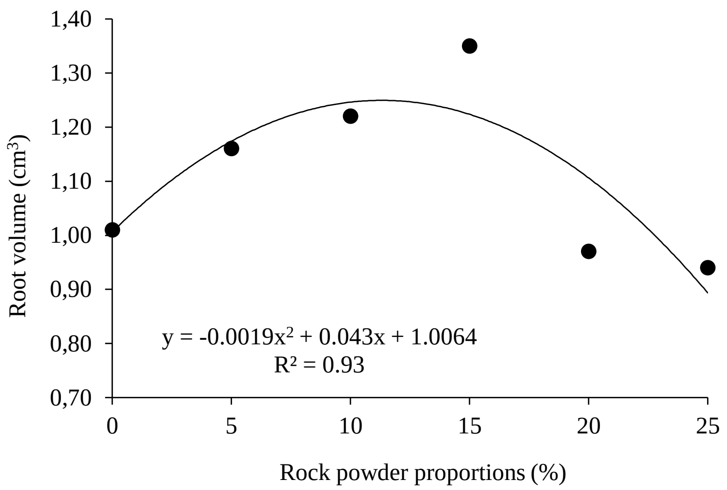

FIGURE 4 - Root volume (RV) of arugula seedlings as a function of rock powder proportions added to the cultivation substrate.

The use of up to 15% of the rock powder container volume provided the best results in the shoot (Figure 3) and in the root system (Figure 4) of arugula seedlings. The physical evaluation of the materials used as growth medium (Table 5) showed that the addition of rock powder to the cultivation substrate increased the density of the materials. The densities (kg m^{-3}) were 298, 348, 431, 449, and 568 for the proportions of 5%, 10%, 15%, 20% and 25% of rock powder, respectively (Table 5). Very dense substrates (>300 kg m^{-3}) impair the root growth of plants by mechanical impediment (FERMINO; KÄMPF, 2012).

Thus, the addition of the remineralizer to the cultivation substrate in proportions greater than 15% compromised the development of the root system (Figure 4) and this reduced the quality of the seedlings obtained (Figure 3). These results support those obtained by Chiomento et al. (2021b), who found a reduction in strawberry yield potential in rock powder proportions equal to or greater than 15%.

Rock powder solubilization involves a process related to biological activities. The use of this input may be inefficient in the absence of cultural practices that stimulate the soil microbiota. Thus, the application of rock powder is not a system of replacing chemical inputs, but a soil management practice for the fertilization of the agroecosystem (KORCHAGIN et al., 2019).

One of the main functions of the container in the formation of seedlings is to protect the roots from mechanical damage, promoting survival in the definitive place of cultivation (SANTOS et al., 2021). Thus, choosing substrates that enhance the development of the shoot and the root system is important to obtain quality seedlings. Therefore, this study indicated that the addition of up to 15% of rock powder to the commercial substrate proved to be a strategic tool to enhance shoot fresh mass and root volume, improving the quality of arugula seedlings.

CONCLUSIONS

There is no interactive effect between substrates and rock powder in the production of arugula seedlings in containers.

Substrates with greater water retention enhance the quality of arugula seedlings because they improve their phytometric morphology.

Proportions of rock powder added to the Horta 2® substrate interfere with the shoot and root system morphology of the seedlings.

The increase in the proportion of this remineralizer up to 15% of the container volume, added to the growth medium, improves the aerial biomass and the root volume of arugula seedlings, 'Donatella' cultivar.

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