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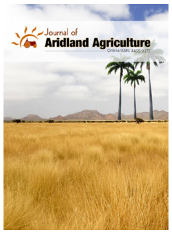
Research Article



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Eruca sativa plants modulate growth and gas exchange when cultivated under salinity stress after leaching fractions

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ABSTRACT

The physiology of rocket plants at different salinity levels through irrigation water and leaching fractions was assessed. Four salinity levels of irrigation water: 0.10, 1.60, 3.10 and 4.60 dS m^{-1} and three leaching fractions: 0, 10 and 20% were applied. The physiological variables analyzed were photosynthetic rate, stomatal conductance, transpiration rate and photosynthetic pigment contents. The growth and biomass production were analyzed by: plant height, number of leaves, leaf area and partitioned and total plant fresh and dry mass, and root to aerial part ratio. The leaching fraction of 10% combined with irrigation with water salinity levels ranging from 0.10 to 0.88 dS m^{-1} resulted in greater plant height, leaf area and root, shoot and total dry mass. The leaching fraction of 20% with irrigation water with salinity levels from 0.10 to 2.7 dS m^{-1} generates higher leaf number, shoot fresh mass, root-to-shoot ratio, stomatal conductance, and photosynthetic rate. Irrigation water with a salinity level of 0.10 dS m^{-1} provides a higher transpiration rate for rocket plants. Irrigation water with a salinity level of 4.6 dS m^{-1} generates higher chlorophyll a, b and total (a + b) and carotenoid contents in rocket plants.

KEYWORDS: Rocket plants, Salinity levels, Photosynthetic rate, Stomatal conductance, Fresh and dry mass

INTRODUCTION

Salinity is a major problem threatening agricultural production worldwide. About 800 million ha including 32 million ha of agricultural lands were affected by intense salt degradation processes (FAO, 2015; Alzahib *et al.*, 2021). Climate change intensifies this process through interference in the biogeochemical cycle of water, soil (soil microorganisms and soil organic carbon), greenhouse gas (GHG) emissions, land desertification, and loss of biodiversity (Haj-Amor *et al.*, 2022). Anthropogenic actions disrupt groundwater basins, which may hinder overall food security and environmental sustainability (Mukhopadhyay *et al.*, 2021).

In many cases, the underserved population makes use of low quality water in irrigation together with agriculture intensification, can cause crop yields reduction up to 58%. A profound change in soil biodiversity, therefore may occur due to severe soil salinity when reaching a critical state of desertification (Shrivastava & Kumar, 2015; Machado & Serralheiro, 2017).

In the 2017 growing season, about 40,000 tons of rocket plants were produced in Brazil (IBGE, 2017). Species within the family Brassicaceae, including rocket plants, are thought to be poorly tolerant to saline environments. Nevertheless, there are limited studies investigated rocket plant management under abiotic stresses, cultivation with low quality water and resistance to such stresses (Moura *et al.*, 2008; Pavão *et al.*, 2019).

The increasing water demand in agriculture resulted in using of low quality water, including saline water (Schiattone *et al.*, 2017; de Oliveira *et al.*, 2021); one of the abiotic stresses that can hamper plant growth and agricultural productivity (Cheng *et al.*, 2021; Lili *et al.*, 2021).

Leaching fraction was used to control salt accumulation in cropping environments through the application of irrigation water depth greater than that required by the crop to penetrate below the root zone and carry away part of the accumulated salts (Medeiros *et al.*, 2010).

Many studies on leaching fractions coupled with water salinity levels in vegetable crops were performed (dos Santos *et al.*, 2016; Santos *et al.*, 2018a; Damasceno *et al.*, 2022), but they are still infrequent. Therefore, the aim of this research was to investigate growth and gas exchange in rocket plants subjected to different salinity levels in irrigation water and leaching fractions.

MATERIALS AND METHODS

The study was carried out in Arapiraca, Alagoas State, Brazil (09°42'02 "S, 36°41'12 "W, 325 m above sea level). According to the Köppen classification, the climate of this region is tropical "As", with a hot and dry period (spring-summer) and a cold and rainy period (autumn-winter). The experiment was performed during the period from July to August 2016 under greenhouse conditions.

The temperature inside the greenhouse ranged 25.4 ºC (6:50 am) to 30.1 ºC (at 4:00 pm) at medium relative humidity: 75%. Medium internal carbon dioxide (CO_2) concentration 303 ppm and global radiation ranged 5 to 28 MJ m^{-2} day^{-1} and photosynthesis active radiation ranged 558 to 678 μmol m^{-2} s^{-1}. The cover of the greenhouse was 120 micron diffuser film and the side screens 50 mesh.

Ultisol - Argisol Red Yellow Dystrophic (Santos *et al.*, 2018b), non-saline and no sodic soil type was used. The Chemical and physical properties of soil 0-0.1 m layer are listed in Table 1.

The experiment was arranged in a completely randomized block design, in a 4x3 factorial scheme with four replications. The treatments were composed of four levels of electrical conductivity of irrigation water (ECw): 0.1, 1.6, 3.1 and 4.6 dS m^{-1} at 25 ºC and three leaching fractions ($LF_{\%}$): LF_0, LF_{10} and LF_{20}, with a total of 48 experimental units. The plot consisted of two polyethylene pots, with one plant in each.

Polyethylene pots with a capacity of 5 liters were filled with 2 cm of gravel and 4 kg of soil. The rocket variety used was the 'Cultivated', commercialized by the company Isla.

Table 1: Chemical and physical properties of soil used in the experiment

pH	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
(H_2O)	g kg^{-3}	mg dm^{-3}	(cmol$_c$ dm^{-3})					
5.4	11.7	9.10	0.45	0.09	1.19	2.21	0.0	1.07
BD	FC	PWP	Sand		Silt		Clay	
kg dm^{-3}	%							
1.40	7.8	4.05	83.48		5.04		11.48	

OM = organic matter, BD = bulk density, FC = field capacity, PWP = permanent wilting point

The irrigation water was prepared based on the relationship between the electrical conductivity of the irrigation water and concentration of sodium chloride (mg L^{-1} = 640 x EC), according to Rhoades and Loveday (1990). The desired conductivity was multiplied by 640 to obtain the amount of sodium chloride ($NaCl^-$ mg L^{-1}) required for each salt level. For the saline level S1, the concentration of salts in the local water supply, with an electrical conductivity of 0.10 dS m^{-1} was applied

The irrigation was applied daily according to the water consumption of the plants as the previous irrigation. The vases perforated in the lower part were inserted with a drain with a diameter of 14 mm, externally connected to a 2 liter collector to obtain the water consumption of the plants and control leaching. The resultant volume was divided by the factors 0.90 and 0.80 (Equation 1), which restored soil moisture to field capacity, obtaining leaching fractions (FL) of 10 and 20%. For plants subjected to treatment FL1 - 0% leaching, the water consumption of treatment S1 (0.10 dS m^{-1}) combined with FL3 - 20% leaching was used in irrigation. The irrigation volumes were calculated according to Equation 1.

$$VI = \left[\left(\frac{VA - VD}{1 - FL}\right)\right] \quad (1)$$

on what, VI is the volume of water to be applied in irrigation (mL); VA is the applied volume (mL), VD is the drained volume (mL) and FL is 0.1 and 0.2 for FL10 and FL20, respectively.

Growth, yield, and physiological variables were assessed. The growth and production parameters were obtained at 30 days after application treatment (DAAT)including, plant height (PA), number of leaves (NL), leaf area (LA), shoot fresh mass (SFM), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), and root to shoot ratio (R/S). The root/shoot ratio was obtained from shoot and root phytomass data. The phytomass of the plant was obtained by drying the material at 60 °C, until constant weight, in an oven with forced air circulation. The physiological variables were measured 15 and 30 days after the application of treatments (DAAT), with infrared gas analyzer - IRGA (LI 6400, LICOR, Lincoln, USA), between 8:00 and 10:00 am, in fully expanded and non-senescent leaves. The photosynthetic rate (A - μmol CO_2 m^{-2} s^{-1}), stomatal conductance (gs - mol H_2O m^{-2} s^{-1}) and transpiration rate (E - mmol H_2O m^{-2} s^{-1}) were assessed. Photosynthetic pigment contents (chlorophylls and carotenoids) were determined 30 days after application treatment (DAAT) according to Arnon (1949). The absorbance was read in a spectrophotometer (BEL Engineering, model UV-M51), at wavelengths of 470, 647, 663 and 710 nm. The calculation of chlorophyll *a* (C_A), chlorophyll *b* (C_B), total chlorophyll (C_T) and carotenoids (C_R) concentration was performed according to the equations established by Lichtenthaler (1987).

Statistical analyses were performed using analysis of variance, F test (P <.05), Tukey's test (P <.05) for the leaching fraction and by regression analysis for the salt levels and the interaction between the factors. The significance of regression coefficients was verified by the t-test (P <.05). All statistical analysis were performed using the statistical software Sisvar (Ferreira, 2014).

RESULTS AND DISCUSSION

The interaction between irrigation water salinity and leaching fraction was significant ($p < .05$) at 30 days after application of treatments (DAAT), for all growth and production variables, for photosynthesis at 15 days and stomatal conductance at 15 and 30 DAAT. As for the isolated factors, the salinity levels of the irrigation water these influenced the transpiration rate at 15 and 30 DAAT, and chlorophylls *a* and *b*, total chlorophyll and carotenoids only at 30 DAAT. Photosynthesis was influenced by salinity and leaching fraction at 30 DAAT (Table 2).

The variable height of rocket plants adjusted the quadratic model in relation to the leaching fractions FL_0 and FL_{10} and linear for FL_{20} (Figure 1a). The 21.2 and 22.3 cm maximum height under FL_0 and $FL1_0$ were scored at salinity levels of 1.54 and 0.88 dS m^{-1}, respectively. While the highest salinity level ($S_{4:}$ 4.60 dS m^{-1}) scored, 17.7 and 18.8 cm, the lowest plant heights respectively. As for FL_{20}, the maximum plant height was 21.2 cm under the highest S_4 level, scoring 7% increment compared to the lowest height, 19.8 cm, obtained in plots irrigated with $S_{1:}$ 0.10 dS m^{-1}. Petretto *et al.* (2019) observed greater height of plants cultivated with non-saline water, 25.9 cm, and the lowest height was seen in plants under the highest water salinity level, 8.0 cm. These

Table 2: Summary of analysis of variance for plant height (HP), number of leaves (NL), leaf area (LA), shoot fresh mass (SFM), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM) root shoot interaction (R/S), chlorophyll *a* (C_A), chlorophyll *b* (C_B), total chlorophyll (C_T) and carotenoid (C_R) - 30 DAAT; photosynthetic rate (*A*), transpiration (*E*), stomatal conductance (*gs*) - 15 and 30 DAAT of rocket plants as a function of levels of electrical conductivity of irrigation water and leaching fractions

Source of variation	DF	Mean Square (30 DAAT)			
		PH	NL	LA	SFM
Salinity Level (SL)	3	10.54**	62,25**	479668.85**	288.64**
Linear Regression	1	17.01**	176.81**	1216238.43**	146.40**
Quadratic Regression	1	12.91**	0.33^{NS}	186875.52**	638.38**
Regression Deviation	1	1.71^{NS}	9.60**	35892.60^{NS}	81.14*
Leaching Fraction (LF)	2	5.47**	21.39**	17773.00^{NS}	60.82*
SL x FL	6	5.42**	7.47**	73092.50**	125.35**
Block	3	0.24^{NS}	1.25^{NS}	45612.18^{NS}	6.44 ^{NS}
Residue	33	0.84	0.90	18889.62	15.33
CV (%)		4.50	4.92	10.45	9.09
		SDM	RDM	TDM	R/S
Salinity Level (SL)	3	13.16 **	0.18**	16.33**	0.00**
Linear Regression	1	33.70 **	0.40**	41.51**	0.00^{NS}
Quadratic Regression	1	0.70 ^{NS}	0.07**	1.24*	0.00**
Regression Deviation	1	5.08 **	0.05**	6.22**	0.00^{NS}
Leaching Fraction (LF)	2	1.35 **	0.08**	2.04**	0.00**
S x FL	6	2.65 **	0.02**	2.83**	0.00**
Bloc	3	0.51 ^{NS}	0.00^{NS}	0.62 ^{NS}	0.00^{NS}
Resídue	33	0.25	0.00	0.29	0.00
C.V. (%)		9.24	6.76	8.92	5.52
		C_A	C_B	C_T	C_R
Salinity Level (SL)	3	8.26**	1.56**	16.85**	0.65**
Linear Regression	1	20.97**	4.57**	45.16**	1.83**
Quadratic Regression	1	1.61 ^{NS}	0.04^{NS}	2.17^{NS}	0.05^{NS}
Regression	1	2.19 ^{NS}	0.09^{NS}	3.22^{NS}	0.09^{NS}
Leaching Fraction (LF)	2	0.23 ^{NS}	0.23^{NS}	0.85^{NS}	0.06^{NS}
S x FL	6	1.64 ^{NS}	0.03^{NS}	1.60^{NS}	0.08^{NS}
Block	3	0.25 ^{NS}	0.05 ^{NS}	0.37^{NS}	0.04^{NS}
Residue	33	0.86	0.09	1.24	0.06
C.V. (%)		18.97	18.65	17.02	17.14

Source of Variation	DF	Mean Square (15 and 30 DAAT)					
		A		*E*		*gs*	
		15 Days	30 Days	15 Days	30 Days	15 Days	30 Days
Salinity Level (SL)	3	70.79**	370.08**	7.14**	17.37**	0.02**	0.05**
Linear Regression	1	172.53**	959.98**	20.90**	44.50**	0.08**	0.14**
Quadratic Regression	1	39.43**	146.92**	0.02^{NS}	7.44**	0.00^{NS}	0.00**
Regression	1	0.42^{NS}	3.34^{NS}	0.51^{NS}	0.18^{NS}	0.00^{NS}	0.00**
Leaching Fraction (LF)	2	1.63^{NS}	12.64**	0.94^{NS}	0.61^{NS}	0.00^{NS}	0.00^{NS}
S x FL	6	11.28*	1.78^{NS}	0.28^{NS}	0.95^{NS}	0.00*	0.00*
Block	3	20.70^{NS}	1.76^{NS}	5.61^{NS}	0.52^{NS}	0.00^{NS}	0.00^{NS}
Residue	33	4.29	2.30	0.64	0.55	0.00	0.00
C.V. (%)		10.43	12.69	16.29	22.35	9.80	15.32

DF - degree of freedom; ** - Significant by teste F at .01; * - Significant by teste F at .05; ^{NS} - Not significant by teste F at .05; CV - coefficient of variation

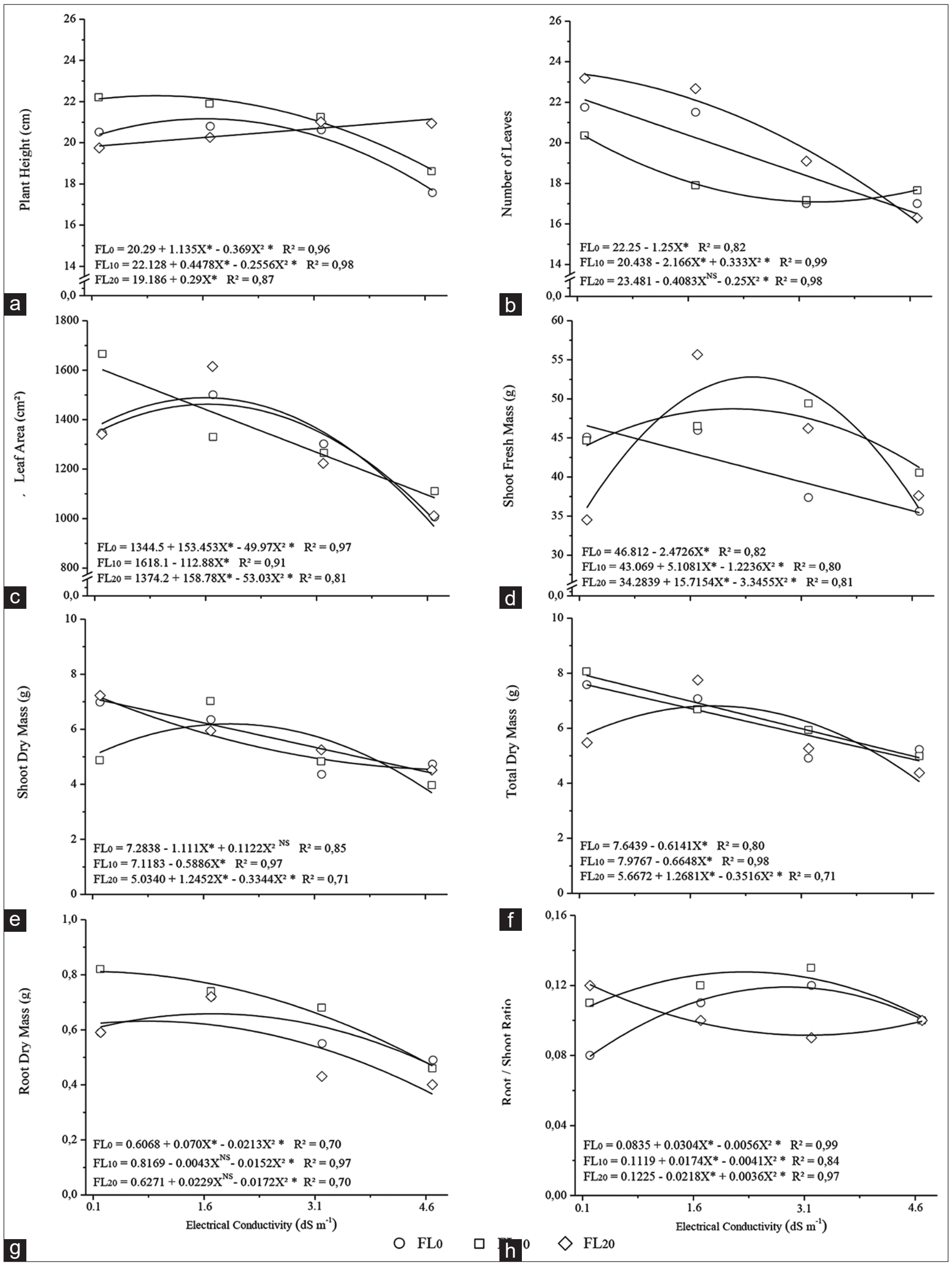

Figure 1: a) Plant height, b) number of leaves, c) leaf area, d) shoot fresh mass, e) shoot dry mass, f) total dry mass, g) root dry mass and h) root/shoot ratio of rocket plants treated with different salinity levels of irrigation water expressed in electrical conductivity (ECw) and leaching fractions, at 30 days after treatment application (DAAT)

values confirm the results obtained in this research for plant height. The researchers also stated that the reduction in height of rocket plants might occur, mainly, due to osmotic stress and ionic toxicity caused salt accumulation.

For the number of leaves, the highest value (23.4) observed under the leaching fraction FL_0 was in plants irrigated with S1. While plants irrigated with S_4 produced 16.3 leaves, scoring 30% lower than S1. In general, the behavior of rocket plants regarding the number of leaves was decreasing. However, under FL_{20} the maximum leaf number was 23.6 at a salinity level of 0.82 dS m^{-1}, an increase of 45% over the lowest leaf number of 16.3 at S_4. FL_{10} did not attenuate the effects of salts on leaf number and FL_0 and finally in FL0 the plants did not show similar behavior to the other treatments (Figure 1b). Researchers state that increasing irrigation water salinity reduces the number of leaves in rocket plants (Schiattone *et al.*, 2017; Júnior *et al.*, 2018), as seen in this research. The initial symptoms of salinity on rocket plants growth occurred through reduction in number and leaf area and number (Schiattone *et al.*, 2017). This was confirmed in this research, plants submitted to the highest level of water salinity, S_4, regardless of the leaching fraction, showed lower number of leaves, while plants under the S_1 level produced higher leaf number.

As for leaf area (LA), the FL_0 and FL_{20} fractions reached maximum values of 1,462 and 1,493 cm^2, respectively, with saline water of electrical conductivity of 1.50. The lowest LA values obtained under these leaching fractions were observed in plants irrigated with the S_4 level, being 993 and 982 cm^2, respectively. These values are 32 and 34% lower compared to the highest values obtained. Under FL_{10}, the highest LA value obtained was 1,606 cm^2, under level S_1. While plants irrigated with the highest saline level, S_4, produced the lowest LA, 1098 cm^2, being 32% lower compared to the highest value observed (Figure 1c). This confirms Schiattone *et al.* (2017), cited in the previous paragraph, in which the researchers emphasize the reduction of leaf area and the number of leaves as primary symptoms of stress in rocket plants when cultivated at salinity levels in water above the tolerable by the crop and that this is an escape mechanism modulated by the plant. It is notable that nevertheless of the leaching fractions, the highest values in leaf area remained close, indicating little interference of this factor in the LA of rocket plants under the conditions studied.

Concerning shoot mass, the maximum fresh mass among the leaching fractions studied was produced by plants under FL_{20}, 52.7 g, and salinity level of 2.30 dS m^{-1}. Whereas the maximum dry mass was 7.2 g, under salinity level S_1 (Figure 1d & e). The maximum root dry mass among the leaching fractions was 0.8 g, produced by plants irrigated with S1: 0.10 dS m^{-1} and FL_{10} (Figure 1f). As for total dry mass, the highest value observed was 7.9 g, in plants irrigated with level S_1 and FL_{10}, and the lowest value was 4.1 g, under level $S_4$and FL_{20}. It represents a decrease in the total dry mass of rocket plants of 48% (Figure 1g). The highest values of root to shoot ratio varied from 0.12 to 0.13 at salinity levels from 0.10 to 2.71 dS m^{-1} and leaching fractions from FL_0 to FL_{20}, respectively (Figure 1h). In general, increasing salinity in irrigation water tends to reduce mass accumulation in plants of the Brassicaceae family, such as rocket plants, as can be observed in other research (Shabani *et al.*, 2013; Júnior *et al.*, 2018), which ratifies the results obtained in this research. Shabani *et al.* (2013) state that the reduction in plant progress in response to salt stress, such as smaller leaf area, causes a reduction in dry mass accumulation in plants, which reduces agricultural productivity. This confirms the results obtained in this research paper, where rocket plants reduced mass accumulation under the highest level of water salinity administered in this research.

The net photosynthetic rate (A) at 15 DAAT adjusted to the quadratic model of FL_0 and FL_{10}, showed similar compared to linear relatedness of FL_{20} (Figure 2a). FL_{20} scored 21.7 μmol CO_2 m^{-2} s^{-1}maximum photosynthetic rate, at 1.54 dS m^{-1} salinity level. In this fraction, the lowest A value was 16.7 μmol CO_2 m^{-2} s^{-1}, at water salinity level S_4, indicating 23% A reduction compared to the maximum value obtained. Under FL_{10} and FL_{20} the maximum value of A was, 22.0 and 23.3 μmol CO_2 m^{-2} s^{-1}, with salinity level of 1.52 dS m^{-1} and S_1, respectively. While, under S_4 there are reductions of 30 and 27% in the value of A, in comparison with FL_{10} and FL_{20}, respectively.

The high levels of sodium and chloride in the soil impair the photosynthetic capacity of rocket plants through hampering important metabolic processes, including the activity of enzymes that participate in CO_2 reduction (Hniličková *et al.*, 2017). Moreover, high levels of salts in the growing environment generate negative osmotic effects on the plant at physiological and biochemical levels. Such osmotic effects induce water stress

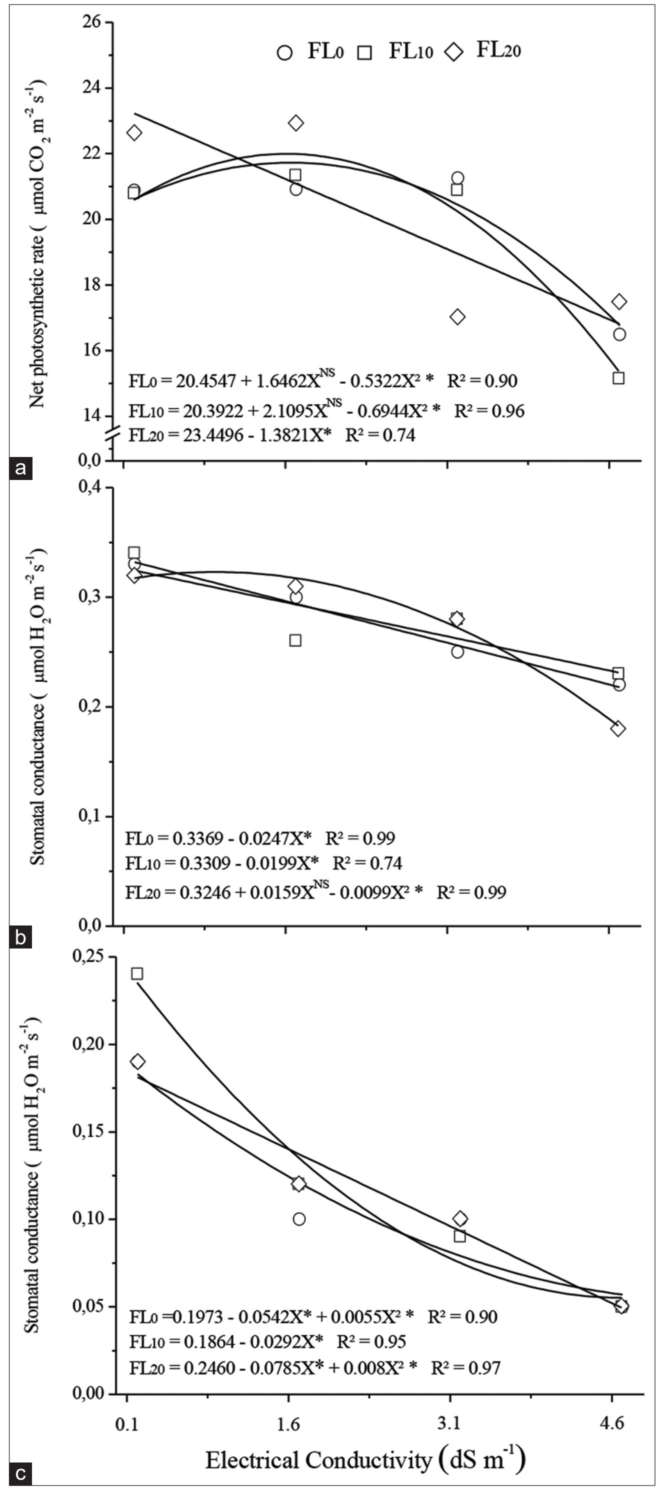

Figure 2: a) photosynthesis and (b and c) stomatal conductance, 15 and 30 days after the application of treatments (DAAT), in rocket plants as a function of salinity levels of irrigation water expressed in electrical conductivity (ECw) and leaching fractions

causing reduced stomatal conductance and increased water use efficiency. They also affect CO_2 assimilation and cause a reduction in photosynthetic rate and, consequently, of photo-assimilates. Similarly, data obtained showed the lower salinity level of irrigation water combined with the higher leaching fraction caused higher photosynthetic rates in rocket plants. Whereas rocket plants treated with higher salinity levels and lower leaching fraction exhibited the lowest rates.

Stomatal conductance (gs) scored 0.33 μmol H_2O m^{-2} s^{-1}highest value, 15 DAAT at FL_0 and $FL_{10,}$ in plants irrigated with S1. While the lowest values were 0.22 and 0.24 μmol H_2O m^{-2} s^{-1}, in plants irrigated with S_4, respectively, indicating 33 and 27% gs reduction when increasing water salinity from 0.10 to 4.60 dS m^{-1}. In this same evaluation period, rocket plants under FL_{20} obtained maximum gs of 0.33 μmol H_2O m^{-2} s^{-1}, with irrigation water salinity level of 0.80 dS m^{-1}. The lowest gs value in these plants was 0.19 μmol H_2O m^{-2} s^{-1}, with salinity level S_4, a value 42% lower when compared to the maximum value obtained under FL_{20} (Figure 2b).

In the gs evaluation performed at 30 DAAT, a quadratic adjustment was observed for the FL_0 and FL_{20} fractions. Plants irrigated with water salinity level $S_{1:}$ 0.10 dS m^{-1} were those ones that presented the highest gs under the two leaching fractions, 0.19 and 0.24 μmol H_2O m^{-2} s^{-1}, respectively. The lowest values in this evaluation, for both fractions, were observed in plants irrigated with $S_{4:}$ 4.60 dS m^{-1}, 0.06 and 0.05 μmol H_2O m^{-2} s^{-1}, respectively. Such gs values represent a reduction of 68 and 79% when compared to the highest values observed. FL_{10} fitted the linear model, the highest gs in plants receiving this fraction was 0.18 μmol H_2O m^{-2} s^{-1}, under S_1, whereas the lowest value verified was 0.05 μmol H_2O m^{-2} s^{-1}, under S4, which indicates 72% decrease in stomatal conductance of rocket plants with increasing water salinity (Figure 2c).

Stomatal conductance (*gs*) scored 0.33 μmol H_2O m^{-2} s^{-1}, highest value, 15 DAAT at FL_0 and FL_{10}, in plants irrigated with S_1. rocket plants under FL_{20} obtained maximum *gs* of 0.33 μmol H_2O m^{-2} s^{-1}, however with irrigation water salinity level of 0.80 dS m^{-1}. At 30 DAAT, under FL_0 and $FL2_0$ fractions, plants irrigated with water salinity level S_1 were those ones that presented the highest *gs* under the two leaching fractions, 0.19 and 0.24 μmol H_2O m^{-2} s^{-1}, respectively. FL_{10} adjusted the linear model, the highest *gs* in plants receiving this fraction was 0.18 μmol H_2O m^{-2} s^{-1}, under S_1. While, in general, the lowest values 15 and 30 DAAT were observed in plants irrigated with S_4 (Figure 2b & c).

Similarly, it was reported stomatal conductance decreased in rocket and other agricultural crops under water salinity levels (Ivanova *et al.*, 2015; Hniličková *et al.*, 2017). Salinity in irrigation water reduced the stomatal conductance of rocket plants through inducing stomatal closure, resulted in lower internal CO_2 concentration, transpiration, and photosynthetic rate of the plant (Sharma *et al.*, 1996; Zelm *et al.*, 2020). Schiattone *et al.* (2017) stated the adequate leaching fractions mitigated the effect of salts on the root system of the crop and maintained the soil closed to field capacity. Thus, the lower water salinity level and the higher leaching fraction rocket plants exhibited higher gs, that favored higher photosynthetic rates.

Accordingly, the first step of plant defense modulation against excess salt in the environment is to block the transport of Na^+ to the aerial part, through apoplastic barriers, including Caspary striations (Krishnamurthy *et al.*, 2011). Secondly, is to dilute Na^+ in the cytoplasm by compartmentalizing salts in the vacuole (Blumwald, 2000). The final step is to exclude Na^+ using an antiporter at the plasma membrane (Byrt *et al.*, 2014)

In the separated analysis of the factors, 30 DAAT, the net photosynthetic rate (A) of rocket plants was higher under FL_0, 13.0 μmol CO_2 m^{-2} s^{-1} (Figure 3a). As for the salinity levels tested in this research, it was observed in plants irrigated with S_1 the highest A, 19.7 μmol CO_2 m^{-2} s^{-1} (Figure 3b). Guimarães *et al.* (2019) indicated, plants under salt stress tend to acclimate to the unfavorable conditions caused by salt accumulation, through decrease the transpiration rate as a result of water stress caused by the osmotic effect and, consequently, reduce the photosynthetic rate. Similarly, the rocket plants treated with the highest salinity level, $S_{4:}$ 4.60 dS m^{-1}, scored lower photosynthesis and transpiration rates (Figure 3).

The transpiration rate (E), at 15 DAAT, was higher in rocket plants irrigated with S_1, 5.8 mmol H_2O m^{-2} s^{-1}, a value that represents an increase of 45% in E in comparison with the rate observed in plots irrigated with S_4, 4.0 mmol H_2O m^{-2} s^{-1} (Figure 3c). In the evaluation performed at 30 DAAT, there was a 14% reduction in E in plants irrigated with S_1, compared with the previous evaluation, at a rate of 5.0 mmol H_2O m^{-2} s^{-1}.

The lowest E value was observed in plants irrigated with S_4, 2.6 mmol H_2O m^{-2} s^{-1}, a value 35% lower compared to that obtained in the first evaluation (Figure 3d). Guimarães *et al.* (2019) reported that high salinity levels in irrigation water generated water stress in the plant and under water deficit conditions. Silva *et al.* (2021) reported that there was a reduction in transpiration rate as one of the primary responses to water deficiency. Similarly, data obtained from rocket plants treated with water salinity levels, showed when water salinity level increased, there was a a decrease in the transpiration rate of the crop so that to optimize water deficiency.

Chen *et al.* (2018), indicated plants are able to adjust their water equilibrium in response to salt stress. Plants adapt to osmotic stress principally by controlling transpiration and accumulating osmotic adjustment substances such as proline. The accumulation of these substances reduces the water potential and maintains the water absorption capacity under salt stress.

Regarding photosynthetic pigments, the lowest values of chlorophyll a (CA) and b (CB), at 30 DAAT, were verified in plants irrigated with water from level S_1 - 0.10 dS m^{-1}, obtaining the values 4.0 and 1.2 g kg^{-1} MS, respectively. Hence, lower value of total chlorophyll (TC), 5.2 g kg^{-1} DM, was observed in S_1. Among the water salinity levels studied, the highest values of CA and CB were 5.8 and 2.1 g kg^{-1} DM, respectively, shown in

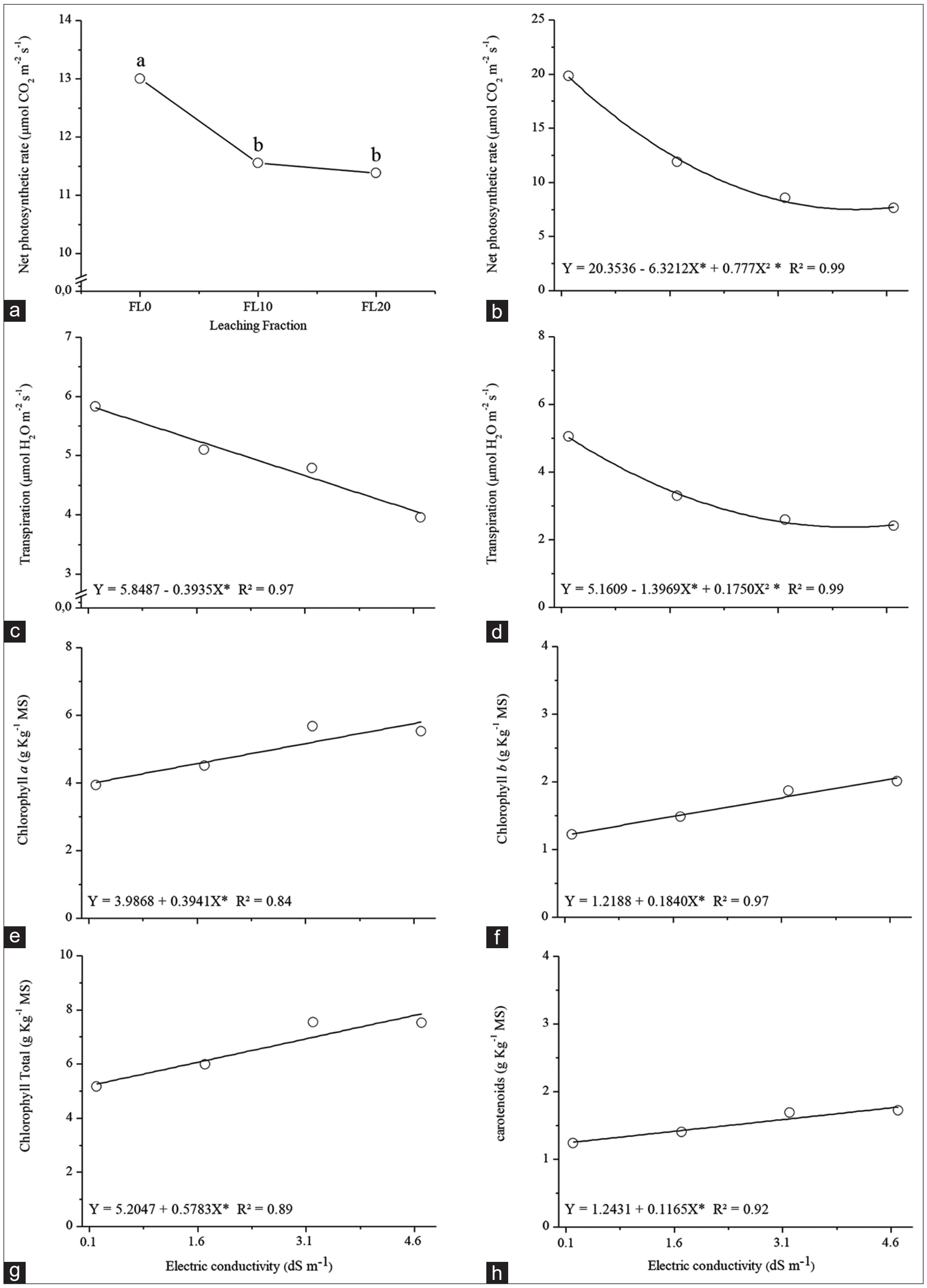

Figure 3: Photosynthesis at 30 DAAT as a function of a) leaching fraction and b) photosynthesis at 30 DAAT and c, d) transpiration at 15 and 30 DAAT and e) chlorophyll a, f) chlorophyll b, g) total chlorophyll and h) carotenoids at 30 DAAT in rocket plants treated with different salinity levels of irrigation water expressed in electrical conductivity (ECw)

plants irrigated with S_4 - 4.60 dS m^{-1}. Hence, in S_4 the highest value of TC, 7.8 g kg^{-1} DM, indicating an increase in TC of 50% in comparison with S_1 (Figure 3e, f & g).

Similarly, the lowest carotenoid value was reported in plants irrigated with S_1, scoring 1.2 g kg^{-1} DM, while the highest 1.7 g kg^{-1} DM value, was scored in plants under S_4 irrigation, showing 29% increase (Figure 3h). The increase in photosynthetic pigments at high water salinity levels may be related to the increase in the number of chloroplasts, suggesting the activation of a protective mechanism for the photosynthetic system in the plant (García-Valenzuela *et al.*, 2005). The increase in photosynthetic pigments tends to increase chlorophyll A in plants because of increasing salinity in the environment to maintain full growth and development and biomass accumulation (Graciano *et al.*, 2011).

Thus, rocket plants cultivated with saline water irrigation might adopt a mechanism to tolerate salt accumulation in the cultural environment and overcome water deficiency. The possible mechanisms adopted include reduction of stomatal conductance, transpiration, number of leaves and leaf area. Besides, the reduction in photosynthetic rate might result in a lower biomass production of the plant. This highlights the importance of adopting adequate management for irrigating rocket plants with saline water by using leaching fractions, which ensures greater agricultural productivity of the crop.

CONCLUSION

A leaching fraction of 10% combined with irrigation with water salinity levels ranging from 0.10 to 0.88 dS m^{-1} results in greater plant height, leaf area and dry mass of roots, shoot and total of rocket plants. The leaching fraction of 20% with irrigation water with salinity levels from 0.10 to 2.7 dS m^{-1} generates higher leaf number, aerial part fresh mass, root to aerial part ratio, stomatal conductance, at 15 and 30 days after application of treatments, respectively, and photosynthetic rate of rocket plants. Irrigation with the lowest water salinity level studied, 0.10 dS m^{-1}, provides higher transpiration rate of rocket plants, at 15 and 30 days after application of the treatments. Irrigation with the highest water salinity level studied, 4.6 dS m^{-1} generates higher chlorophyll a, b and total (a + b) and carotenoids contents in rocket plants.

REFERENCES

Alzahib, R. H., Migdadi, H. M., Al Ghamdi, A. A., Alwahibi, M. S., Ibrahim, A. A., & Al-Selwey, W. A. (2021). Assessment of morpho-physiological, biochemical and antioxidant responses of tomato landraces to salinity stress. *Plants, 10*(4), 696. https://doi.org/10.3390/plants10040696

Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidade in *Beta vulgaris*. *Plant Physiology, 24*(1), 1-15. https://doi.org/10.1104/pp.24.1.1

Blumwald, E. (2000). Sodium transport and salt tolerance in plants. *Current Opinion in Cell Biology, 12*(4), 431-434. https://doi.org/10.1016/S0955-0674(00)00112-5

Byrt, C. S., Xu, B., Krishnan, M., Lightfoot, D. J., Athman, A., Jacobs, A. K., Watson-Haigh, N. S., Plett, D., Munns, R., Tester, M., & Gilliham, M. (2014). The Na^+ transporter, TaHKT1;5-D, limits shoot Na^+ accumulation in bread wheat. *The Plant Journal, 80*(3), 516-526. https://doi.org/10.1111/tpj.12651

Chen, M., Yang, Z., Liu, J., Zhu, T., Wei, X., Fan, H., & Wang, B. (2018). Adaptation mechanism of salt excluders under saline conditions and its applications. *International Journal of Molecular Sciences, 19*(11), 3668. https://doi.org/10.3390/ijms19113668

Cheng, M., Wang, H., Fan, J., Wang, X., Sun, X., Yang, L., Zhang, S., Xiang, Y., & Zhang, F. (2021). Crop yield and water productivity under salty water irrigation: A global meta-analysis. *Agricultural Water Management, 256*, 107105. https://doi.org/10.1016/j.agwat.2021.107105

Damasceno, L. F., Cova, A. M. W., Gheyi, H. R., Almeida, W. F. D., Dias, J. A. A. L., & Ribeiro, V. D. S. (2022). Production and water consumption of eggplant under salt stress and continuous drip and pulse drip irrigation. *Revista Caatinga, 35*(2), 450-459. https://doi.org/10.1590/1983-21252022v35n220rc

de Oliveira, M. A. D., Carneiro, P. T., Alves, M. C. J. L., e Silva, T. V., Neto, G. da C. G., Matos, T. J. R., Souza, M. A., dos Santos, A. F., da Costa, J. G., & Pavão, J. M. da S. J. (2021). Physiological indicators in two lettuce cultivars under saline stress. *Journal of Agricultural Science, 13*(4), 52-63. https://doi.org/10.5539/jas.v13n4p52

dos Santos, D. P., dos Santos, C. S., da Silva, P. F., Pinheiro, M. P. M. A., & Santos, J. C. (2016). Crescimento e fitomassa da beterraba sob irrigação suplementar com água de diferentes concentrações salinas. *Revista Ceres, 63*(4), 509-516. https://doi.org/10.1590/0034-737X201663040011

FAO. (2015). *Status of the World's Soil Resources (SWSR) – Main Report*. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils. Rome, Italy: FAO. Retrieved from https://www.fao.org/3/i5199e/I5199E.pdf

Ferreira, D. F. (2014). Sisvar: a guide for its bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia, 38*(2), 109-112. https://doi.org/10.1590/S1413-70542014000200001

García-Valenzuela, X., García-Moya, E., Rascón-Cruz, Q., Herrera-Estrella, L., & Aguado-Santacruz, G. A. (2005). Chlorophyll accumulation is enhanced by osmotic stress in graminaceous chlorophyllic cells. *Journal of Plant Physiology, 162*(6), 650-656. https://doi.org/10.1016/j.jplph.2004.09.015

Graciano, E. S. A., Nogueira, R. J. M. C., Lima, D. R. M., Pacheco, C. M., & Santos, R. C. (2011). Crescimento e capacidade fotossintética da cultivar de amendoim BR 1 sob condições de salinidade (Growth and photosynthetic capacity of the peanut cultivar BR 1 under saline conditions). *Revista Brasileira de Engenharia Agrícola e Ambiental, 15*(8), 794-800. https://doi.org/10.1590/S1415-43662011000800005

Guimarães, R. F. B., Júnior, S. de O. M., do Nascimento, R., de Melo, D. F., Ramos, J. G., & de Andrade, J. R. (2019). Trocas gasosas em cultivares de alface crespa em cultivo hidropônico com água salina (Leaf gas exchange of curly lettuce cultivars in hydroponic cultivation with saline water). *Revista Brasileira de Agricultura Irrigada, 13*(4), 3599. https://doi.org/10.7127/RBAI.V13N4001091

Haj-Amor, Z, Araya, T., Kim, D.-G., Bouri, S., Lee, J., Ghiloufi, W., Yang, Y., Kang, H., Jhariya, M. K., Banerjee, A., & Lal, R. (2022). Soil salinity and its associated effects on soil microorganisms, greenhouse gas emissions, crop yield, biodiversity and desertification: A review. *Science of the Total Environment, 843*, 156946. https://doi.org/10.1016/j.scitotenv.2022.156946

Hniličková, H., Hnilička, F., Martinkova, J., & Kraus, K. (2017). Effects of salt stress on water status, photosynthesis and chlorophyll fluorescence of rocket. *Plant, Soil and Environment, 63*(8), 362-367. https://doi.org/10.17221/398/2017-PSE

IBGE. (2017). Instituto Brasileiro de Geografia e Estatística. 2017. *Censo agropecuário 2017*. Rio de Janeiro, Brazil: IBGE.

Ivanova, K., Anev, S., Tzvetkova, N., Georgieva, T., & Markovska, Y. (2015). Influence of salt stress on stomatal, biochemical and morphological factors limiting photosynthetic gas exchange in Paulownia Elongata x Fortunei. *Comptes rendus de l'Académie Bulgare des Sciences, 68*(2), 217-224.

Júnior, J. E. C., Júnior, J. A. S., Martins, J. B., de França e Silva, E. F., & de Almeida, C. D. G. C. (2018). Rocket production in a low cost hydroponic system using brackish water. *Revista Caatinga, 31*(4), 1008-1016. https://doi.org/10.1590/1983-21252018v31n424rc

Krishnamurthy, P., Ranathunge, K., Nayak, S., Schreiber, L., & Mathew, M. K. (2011). Root apoplastic barriers block Na+ transport to shoots in rice (*Oryza sativa* L.). *Journal of Experimental Botany, 62*(12), 4215-4228. https://doi.org/10.1093/jxb/err135

Lichtenthaler, H. K. (1987). Chlorophyll and carotenoids: pigments of photosynthetic biomembranes. *Methods in Enzymology, 148*, 350-382. https://doi.org/10.1016/0076-6879(87)48036-1

Lili, Z., Peiling, Y., Wengang, Z., Yunkai, L., Yu, L., & Chong, Z. (2021). Effects of water salinity on emitter clogging in surface drip irrigation systems. *Irrigation Science, 39*, 209-222. https://doi.org/10.1007/s00271-020-00690-3

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil Salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae, 3*(2), 30. https://doi.org/10.3390/horticulturae3020030

Medeiros, J. F., Nascimento, I. B., & Ghery, H. R. (2010). Manejo do solo-água-planta em área afetadas por sais. In H. R. Gheyi, N. S. Dias & C. F. Lacerda (Eds.), *Manejo da salinidade na agricultura: estudos básicos e aplicados* (pp. 279-302). Fortaleza, Brazil: INCT Sal.

Moura, K. K. C. de S., Neto, F. B., Pontes, F. S. T., de Lima, J. S. S., & Moura, K. H. S. (2008). Avaliação econômica de rúcula sob diferentes espaçamentos de plantio. *Revista Caatinga, 21*(2), 113-118.

Mukhopadhyay, R., Sarkar, B., Jat, H. S., Sharma, P. C., & Bolan, N. S. (2021). Soil salinity under climate change: challenges for sustainable agriculture and food security. *Journal of Environmental Management, 280*, 111736. https://doi.org/10.1016/j.jenvman.2020.111736

Pavão, J. M. da S. J., de Castro, E. M., Anna, S. A. C. S., Bomfim, T. R. de P., dos Santos, A. F., da Costa, J. G., Souza, M. A., & Rocha, T. J. M. (2019). Anatomical aspects of the ginger flower *Etlingera elatior* (Jack.) RM Smith, acclimatization with the usage of different nutritive solutions. *Emirates Journal of Food and Agriculture, 31*(9), 708-717. https://doi.

org/10.9755/ejfa.2019.v31.i9.2010

Petretto, G. L., Urgeghe, P. P., Massa, D., & Melito, S. (2019). Effect of salinity (NaCl) on plant growth, nutrient content, and glucosinolate hydrolysis products trends in rocket genotypes. *Plant Physiology and Biochemistry, 141*, 30-39. https://doi.org/10.1016/j.plaphy.2019.05.012

Rhoades, J. D., & Loveday, L. (1990). Salinity in irrigated agriculture. In B. A. Stewart & D. R. Nielsen (Eds.), *Irrigation of agricultural crops* (Vol. 30, pp. 1089-1142). Madison: American Society of Agronomists.

Santos, H. G., Jacomine, P. K. T., Anjos, L. H. C., Oliveira, V. A., Lumbreras, J. F., Coelho, M. R., & Cunha, T. J. F. (2018a). *Sistema Brasileiro de Classificação de Solos.* (5th ed.). Brasília, Brazil: Embrapa.

Santos, R. S. da S., Dias, N. da S., Duarte, S. N., Lima, C. J. G. de S., Fernandes, C. dos S., & de Miranda, J. H. (2018b). Cultivo da rúcula em substrato de fibra de coco sob solução nutritiva salina. *Revista Cultura Agronômica, 27*(1), 12-21. https://doi.org/10.32929/2446-8355.2018v27n1p12-21

Schiattone, M. I., Candido, V., Cantore, V., Montesano, F. F., & Boari, F. (2017). Water use and crop performance of two wild rocket genotypes under salinity conditions. *Agricultural Water Management, 194*, 214-221. https://doi.org/10.1016/j.agwat.2017.09.009

Shabani, A., Sepaskhah, A. R., & Kamgar-Haghighi, A. A. (2013). Growth and physiologic response of rapeseed (*Brassica napus* L.) to deficit irrigation, water salinity and planting method. *International Journal of Plant Production, 7*(3), 569-596. https://doi.org/10.22069/ijpp.2013.1119

Sharma, S. K. (1996). Soil salinity effects on transpiration and net photosynthetic rates, stomatal conductance and Na^+ and Cl^- contents in durum wheat. *Biologia Plantarum, 38*(4), 519-523. https://doi.org/10.1007/BF02890599

Shrivastava, P., & Kumar, R. (2015). Soil salinity: a serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences, 22*(2), 123-131. https://doi.org/10.1016/j.sjbs.2014.12.001

Silva, R. B., Teodoro, I., de Souza, J. L., Junior, R. A. F., Magalhaes, I. D., dos Santos, M. A., Lyra, G. B., Filho, G. M., de Souza, R. C., Silva, L. K. dos S., Santos, J. V., & de Oliveira, J. D. S. (2021). Physiological and productive aspects of cassava under different irrigation levels. *Bragantia, 80*, e5321. https://doi.org/10.1590/1678-4499.20200501

van Zelm, E., Zhang, Y., & Testerink, C. (2020). Salt Tolerance mechanisms of plants. *Annual Review of Plant Biology*, 71, 403-433. https://doi.org/10.1146/annurev-arplant-050718-100005