Hydroponic cultivation of coriander intercropped with rocket subjected to saline and thermal stresses in the root-zone

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ABSTRACT

An experiment was carried out in a randomized blocks design, aiming at evaluation of the cultivation of coriander intercropped with rocket subjected to saline and thermal stresses in the root-zone. Six treatments were evaluated, as follows: four treatments consisted of the combinations of two levels of electrical conductivity of water (ECw 0.3 and 6.5 dS m^{-1}) with two root-zone temperatures – RZT (ambient: < 25 °C and constant at 30 °C). The respective waters were used to prepare the nutrient solution and to replenish the water consumed. In the other two treatments the cultivation was performed at ambient RZT, one with 0.3 dS m^{-1} level used to prepare the solution and 6.5 dS m^{-1} level to replenish the consumption, and other with 6.5 dS m^{-1} level used to prepare the solution and 0.3 dS m^{-1} level to replenish the water consumed. Plant height, stem diameter, water content in shoot, fresh and dry matter of shoot, and tolerance index of saline and thermal stresses were evaluated. The coriander was more tolerant to combined stresses than the rocket. For the isolated stresses, there was a greater reduction in the production of both crops as a function of salinity than by thermal stress.

Keywords: *Coriandrum sativum* L.; *Eruca sativa* Mill.; heat stress; marketable production; salt stress.

INTRODUCTION

In many parts of the world, coriander (*Coriandrum sativum* L.) (Nguyen *et al*., 2020) and rocket (*Eruca sativa* Mill.) (Bonasia *et al*., 2017) are consumed in green salads. In rural communities in the Brazilian semiarid region, the cultivation of these leafy vegetables, as well as others (e.g., chives and lettuce), has been the main source of income for small family farming. Due to the scarcity of fresh water in this region, brackish waters have often been used for irrigation of these vegetables (Silva *et al*., 2018). However, this type of water should be used rationally, as it has generally reduced crop yield.

To mitigate the negative effects of salinity on crop yield (Kitayama *et al*., 2020), different strategies have been used: for example, the alternation in the use of fresh and brackish waters according to crop growth stage (Li *et al*., 2019), as well as the transition to other cultivation systems, such as hydroponics (Atzori *et al*., 2019; Santos *et al*., 2019; Bione *et al*., 2021). In hydroponic cultivation, it takes into account the following hypothesis: there is no retention energy (matric potential) when plants are directly cultivated in nutrient solution (Silva *et al*., 2020a), conferring a possible higher tolerance of plants to salinity compared to traditional soil cultivation (Freitas *et al*., 2019).

Under hydroponic conditions, several studies have been conducted with different strategies aimed at the combined use of fresh and brackish waters, such as: using fresh water in the preparation of the nutrient solution and brackish waters only to replenish the water consumed by plants, e.g., coriander (Silva *et al*., 2015); using brackish waters only in the preparation of the solution and fresh water to replenish the water consumed, e.g., rocket (Jesus *et al*., 2015), parsley (Martins *et al*., 2019) and chives (Sil-

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va Júnior *et al*., 2019); and exclusive use of brackish waters, e.g., lettuce (Soares *et al*., 2015), coriander (Silva *et al*., 2016a; Silva *et al*., 2018; Silva *et al*., 2020a), rocket (Campos Júnior *et al*., 2018) and chicory (Alves *et al*., 2019; Silva *et al*., 2020b).

The high temperatures in arid and semi-arid regions may be a limitation for the hydroponic cultivation when brackish waters are used, because the rise in temperature of the nutrient solution further increases salinity in the cultivation medium (Cocetta *et al*., 2018), as a consequence of the increase in root-zone temperature. Several studies have been conducted with different plant species to evaluate the effect of root-zone temperature, such as those with lettuce (Sakamoto & Suzuki, 2015; Silva *et al*., 2016b), spinach (Ito *et al*., 2013), rocket (He *et al*., 2016), and coriander (Nguyen *et al*., 2019; Nguyen *et al*., 2020; Silva *et al*., 2020a).

Despite the large number of studies involving the isolated effects of salt or thermal stresses in the root-zone, under natural conditions plants are often exposed to complex interactions that may involve the combination of different abiotic stresses. In this context, this study was conducted with the aim to evaluate the effects of combined stress of salinity and root-zone temperature on the growth, production, and quality of intercropped coriander and rocket plants under different strategies of brackish water use.

MATERIALS AND METHODS

Study site description

One experiment was conducted concomitantly with coriander (*Coriandrum sativum* L.) and rocket (*Eruca sativa* Mill.) under hydroponic conditions in a greenhouse, from June to July 2018 (winter season). The study site was in the experimental area of the Post Graduate Program in Agricultural Engineering of the Federal University of Recôncavo of Bahia, Cruz das Almas, Bahia, Brazil (12º 40’ 19" S, 39º 06’ 23" W, and at an altitude of 220 m above mean sea level).

During the experiment, inside the greenhouse, the air temperature and relative air humidity varied from 19.0 to 34.5 °C and 42.5 to 95.7%, with mean values of 22.1 ± 3.0 °C and 83.1 ± 12.7%, respectively. The data were continuously monitored using a HMP45C thermo-hygrometer sensor (Vaisala Inc., Helsinki, Finland) connected to a CR 1000 model datalogger (Campbell Scientific Inc., Logan, Utah, USA).

Experimental design and structure used

The experiment was carried out in a randomized block design, with five replicates. Six treatments were evaluated, as follows: four treatments consisted of the combinations of two levels of electrical conductivity of water (ECw 0.3 dS m^{-1} – low salinity water and 6.5 dS m^{-1} – brackish water containing NaCl) with two root-zone temperatures – RZT (ambient: < 25 °C and constant at 30 °C). The respective waters were used to prepare the nutrient solution and to replenish the water consumed. In the other two treatments the cultivation was performed at ambient RZT, one with ECw of 0.3 dS m^{-1} used to prepare the solution and ECw of 6.5 dS m^{-1} to replenish the evapotranspiration, and other with ECw of 6.5 dS m^{-1} used to prepare the solution and ECw of 0.3 dS m^{-1} to replenish the water consumed by plants, as described in Table 1.

In principle, these last two treatments would be under constant RZT of 32 ºC (without salt stress – 0.3 dS m^{-1} and with salinity water – 6.5 dS m^{-1}) according to a previous study (Silva *et al*., 2020a). However, a day before the transplanting, when the heating of the nutrient solutions started, there was some problem in the electrical installations, thus, it was not possible for all heaters to function simultaneously, as per respective treatments. Therefore, these strategies were employed to combine low salinity and brackish waters.

The water salinity level of 6.5 dS m^{-1} was adopted based on a previous study (Silva *et al*., 2018), corresponding to a relative fresh matter yield of approximately 60% for coriander under hydroponic conditions.

A hydroponic system with the Nutrient Film Technique (NFT) was used, with 6-m long channels made of PVC pipes of 0.075 m in diameter, and a 3.0% slope. More details of the experimental structure can be seen in Silva *et al*. (2020a), including the details of the heating system of nutrient solution.

Crop conduction and nutrient solution management

The coriander cultivar Verdão and rocket cultivar Folha Larga (Feltrin® Sementes, Farroupilha, Brazil) were sown on June 1, 2018. The sowing was performed in 80-mL plastic cups containing coconut fiber substrate of home fabrication (with 15 seeds per cup), procedure similar to that adopted by Silva *et al*. (2020a).

Table 1: Description of treatments, root-zone temperature (RZT) and strategies for use of fresh and brackish waters to prepare the nutrient solution (Psol) and/or for replenishment of the water consumed (Rwc)

Treatments	**RZT**	**Psol**	**Rwc**
		ECw (dS m^{-1}) at 25 ºC	
T1	Ambient	0.3	0.3
T2	Ambient	6.5	6.5
T3	30 ºC	0.3	0.3
T4	30 ºC	6.5	6.5
T5	Ambient	0.3	6.5
T6	Ambient	6.5	0.3

The rocket seedlings were irrigated daily with tap water (ECw of 0.3 dS m^{-1}) during the first five days; for another five days the nutrient solution of Furlani *et al*. (1999) for leafy vegetables at 50% concentration was applied to prevent nutritional deficiencies. For the coriander, the seedlings were irrigated with tap water until transplanting to the hydroponic system. Based on previous studies (Silva *et al*., 2016a; Silva *et al*., 2018; Silva *et al*., 2020a), in the production of coriander seedlings, there was no need to apply a nutrient solution before transplanting.

At 10 days after sowing (DAS), coriander and rocket seedlings were transplanted into the hydroponic system. Thinning was previously performed, leaving 10 seedlings per cup for rocket, according to Jesus *et al*. (2015), and 12 seedlings per cup for coriander, as recommended by Silva *et al*. (2016c). Ten cups with seedlings of each crop were distributed alternately in each hydroponic channel and maintaining a distance of 0.25 m between plants.

The brackish water (ECw of 6.5 dS m^{-1}) was prepared by addition of NaCl in tap water (ECw of 0.3 dS m^{-1}). After that, fertilizer salts were added to these waters, using as reference the standard nutrient solution recommended by Furlani *et al*. (1999), and the observed electrical conductivity of the solutions (ECsol) are shown in Table 2. More details of the preparation and management of the solution can be seen in Silva *et al*. (2020a).

Variables evaluated

Harvests were carried out at 10, 15, 20 and 25 days after transplanting (DAT). The strategy of performing four harvests along the experiment was to assess the possibility of early harvest (in the case of the treatments without salt and thermal stresses) or to maintain plants in the hydroponic system over a long exposure period of these stresses (until to reach the ideal weight for marketing).

In each harvest (in each plot), two bunches of each crop (coriander and rocket) were collected, to determine: stem diameter (SD), plant height (PH), and shoot fresh matter (SFM) and shoot dry matter (SDM) of the bunch of plants. In each bunch the SD was measured of three plants individually at height of 3 cm above the substrate level. The measurements of PH, SD and SDM were carried out according to Silva *et al*. (2020a).

The water content in shoot (WCS) based on the relationship ([(SFM – SDM)/SFM] × 100) was determined, as described Nguyen *et al*. (2020).

The tolerance index (TI) based on the SFM and SDM also was determined, obtained for each treatment of isolated or combined stresses of salinity and root-zone temperature compared to the control (without salt and ambient RZT stress), based on the relationship described by Al-Garni *et al*. (2019).

Statistical analysis

The data were subjected to analysis of variance by F-test ($p < 0.05$) and the means were compared by the Scott-Knott test ($p < 0.05$). All statistical analyses were performed using R-statistical software version 3.6.3.

RESULTS AND DISCUSSION

Visual quality of the plants

According to visual aspect of coriander (Figure 1A) and rocket (Figure 1B) plants, there were no symptoms of toxicity due to salinity and/or high constant RZT of 30 ºC. These results are important as the visual quality of leafy vegetables is a fundamental requirement of the consumer market because. This is a characteristic to be considered for the commercialization of plants (D'Imperio *et al*., 2016), especially when plants are grown under salt stress (D'Imperio *et al*., 2018).

Under hydroponic conditions, the root-zone temperature plays an important role, in which, during the hot season the temperature of the nutrient solution could be too different from that required for optimum plant growth (Costa *et al*., 2011). In the present study, the bulky aspect and light color of roots (Figures 1A and 1B) can be one indicative that the dissolved oxygen (DO) levels in the nutrient solution were adequate for plant growth. This is an important point to be highlighted, because the DO levels in the solution are inversely correlated with RZT (Sakamoto *et al*., 2016). In other words, with the increase

Table 2: Actual root-zone temperature (ARZT), initial solution EC ($ECsol_{initial}$) and solution EC at the end ($ECsol_{end}$) of experiment

Treatments	ARZT	$ECsol_{initial}$	$ECsol_{end}$	Variations in ECsol
	(ºC)	(dS m^{-1}) at 25 ºC		
T1	23.90 ± 0.36#	2.50	1.92	- 0.58
T2	24.00 ± 0.55	8.90	9.75	+ 0.85
T3	30.17 ± 0.32	2.50	2.77	+ 0.27
T4	30.35 ± 0.24	8.90	11.10	+ 2.20
T5	23.51 ± 0.33	2.50	3.12	+ 0.62
T6	24.26 ± 1.03	8.90	8.60	- 0.30

Details of treatments T1, T2, T3, T4, T5 and T6 are described in the Table 1. # mean ± standard deviation.

in temperature during the day, there is a reduction in DO concentration, as observed in an earlier experiment with coriander (Silva *et al*., 2020c).

The growing period in the year also influences the quality of plants produced under salt and/or heat stresses. An example of this is that Bonasia *et al*. (2017) observed a better visual quality of rocket plants in the autumn-winter period (from the mid cycle until the harvest, temperatures frequently dropped below 5 ºC as minimum values) compared to winter-spring (maximum temperatures were frequently higher than 20 ºC) under salinity of 3.5 and 4.5 dS m^{-1} (with NaCl), respectively. In the study conducted by Nguyen *et al*. (2020) with coriander for 18 days, plants subjected to RZT at 35 ºC during the last six days of the cycle showed yellowish leaves and dark roots.

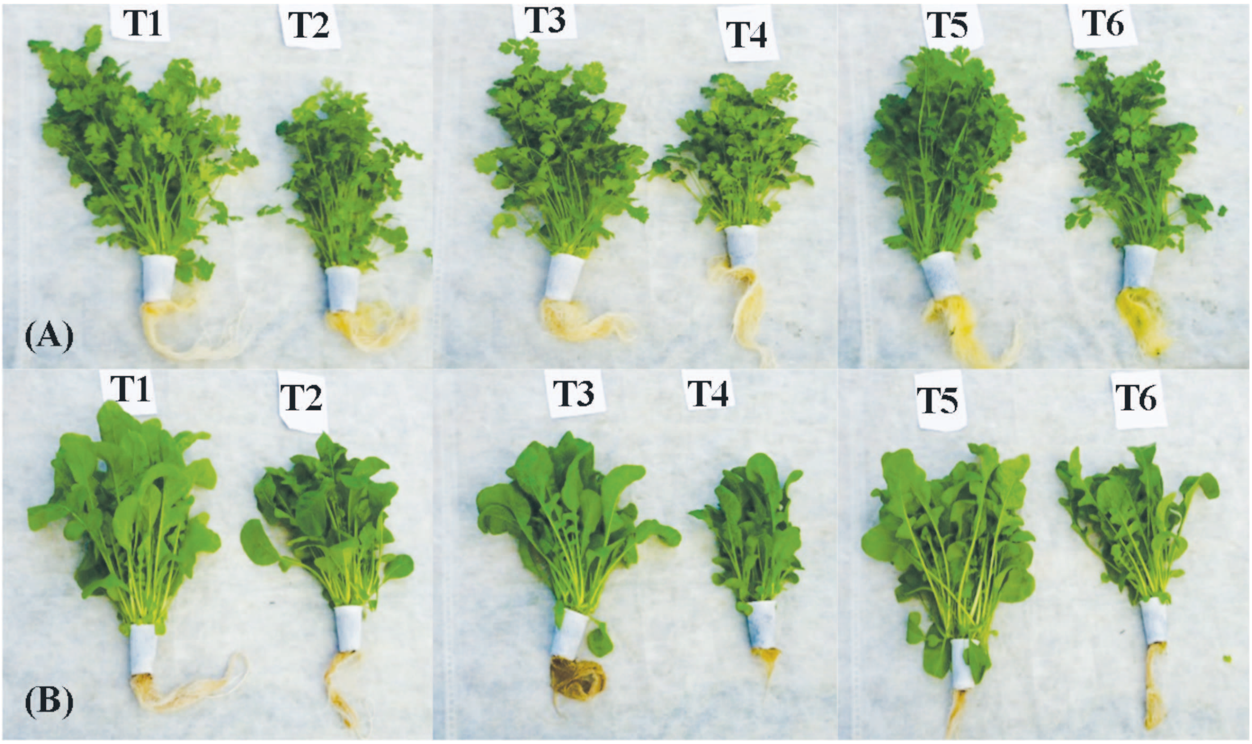
Growth parameters

The plant height of coriander (Figure 2A) and rocket (Figure 2B) was significantly affected ($p < 0.01$) by treatments in all evaluated periods. There was also a significant effect ($p < 0.01$) on the stem diameter of both crops, except at 10 DAT for coriander (Figure 2C) and at 15 DAT for rocket (Figure 2D).

The results show that the plant height (Figure 2B) and stem diameter (Figure 2D) of rocket decreased more drastically under the combined stresses (T4). For coriander (Figures 2A and 2C), the reduced growth patterns were similar for T2, T4 and T6. In the case of T6, the replacement with fresh water (ECw of 0.3 dS m^{-1}) along the coriander cycle did not promote any growth gain when compared to the exclusive use of brackish water with ECw of 6.5 dS m^{-1} (T2).

In studies with the same crops used in the present study, different responses to salinity in the vegetative growth have been reported (Silva *et al*., 2015; Silva *et al*., 2016a; Silva *et al*., 2018; Ahmadi & Souri, 2018; Ghazi, 2018). The different results show that the effect of salt stress varies among species (Ashraf *et al*., 2020), among their organs (Bulgari *et al*., 2019; Alisofi *et al*., 2019), and also as a function of the duration of salt stress imposition (Negrão *et al*., 2017; Shaukat *et al*., 2019).

In the present study, under RZT of 30 ºC (T3) the means of plant height and stem diameter of the coriander (Figures 2A and 2C, respectively) and rocket (Figures 2B and 2D, respectively) were similar to T1 (ECw of 0.3 dS m^{-1} and ambient RZT). These results reinforce those of the other studies, which reported no significant changes in the growth parameters of several plant species subjected to different RZT, such as leaf area and number of leaves in lettuce (Sun *et al*., 2016), stem diameter in lettuce (Sakamoto & Suzuki, 2015), and plant height in coriander under RZT up to 30 ºC (Nguyen *et al*., 2020).



Details of treatments T1, T2, T3, T4, T5 and T6 are described in the Table 1.

Figure 1: The visual aspect of the coriander (A) and rocket (B) plants subjected to stresses of root-zone temperature and salinity and different strategies of use of brackish water, at harvest (25 days after transplanting).

Water content in shoot

Water content in shoot (WCS) of coriander (Figure 3A) and rocket (Figure 3B) plants was significantly affected by treatments, except at 15 DAT for coriander. For coriander, at 10 DAT (T1 and T3), 20 DAT (T1, T3 and T5) and 25 DAT (T1 and T5), these treatments stood out with the highest means of WCS. For rocket, at 10 DAT the lowest values of WCS were observed only in T4, while at 15 and 20 DAT were observed in T2 and T4. At 25 DAT, the highest means of WCS were obtained for T1 and T5.

The water content is associated with the water holding capacity in the tissue of plants, and the higher this content, the better their water status (Souza *et al.*, 2020). In the present study, the values of WCS varied between 90 and 94% for coriander (Figure 3A) and between 92 and 95% for rocket (Figure 3B). These values point to a large amount of water stored in plant tissues, which is an important result because in various regions of the world, the part of greatest commercial interest in these crops is the fresh matter.

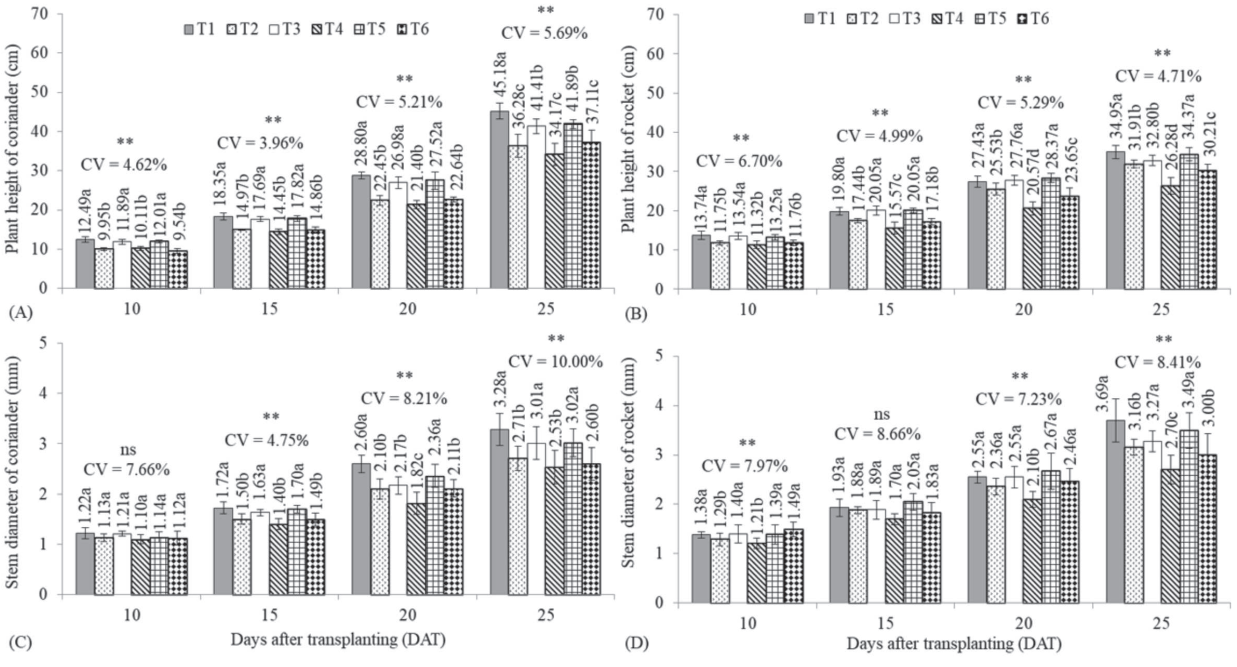
With the exposure of plants to salt stress, there was a reduction in water content due to the dehydration of cells (Azizi *et al.*, 2017; Mehrabani *et al.*, 2018). In the present study, the greatest reductions in WCS occurred at 25 DAT under combined stresses (T4), compared to the means of T1 and T5, of the order of 1.77 and 1.93% for coriander (Figure 3A) and rocket (Figure 3B), respectively.

These reductions in WCS of coriander (Figure 3A) and rocket (Figure 3B) plants recorded in the present study can be considered low, reinforcing the results of Silva *et al*. (2013), who reported a 1.87% decrease in the WCS of rocket under higher ECsol level (10.5 dS m^{-1} with NaCl) in comparison to the control (ECsol of 1.8 dS m^{-1}) in NFT hydroponics.

Considering the isolated effects, in general, the WCS was lower under salinity with exclusive use of brackish water (T2) compared to T1, while only at 25 DAT there were reductions due to constant RZT at 30 ºC (T3) for both coriander (Figure 3A) and rocket (Figure 3B). The absence of significant difference between the means of the WCS as a function of the root-zone temperatures up to 20 DAT reinforces the results obtained in other studies with coriander. Under RZT varying between 25 ºC (Nguyen *et al*., 2019) and 30 ºC (Nguyen *et al*., 2020) verified values of WCS of approximately 90%.

Biomass production and tolerance index

The shoot fresh matter (SFM) and shoot dry matter (SDM) of coriander (Figures 4A and 4C) and rocket (Figures 4B and 4D), and the tolerance index based on the SFM



Details of treatments T1, T2, T3, T4, T5 and T6 are described in the Table 1; CV - coefficient of variation; ** - significant at $p < 0.01$ and ns - not significant by F-test; means followed by the same letter are not significantly different at $p = 0.05$ by Scott-Knott test; vertical bars indicate the means ± standard deviation (n = 5).

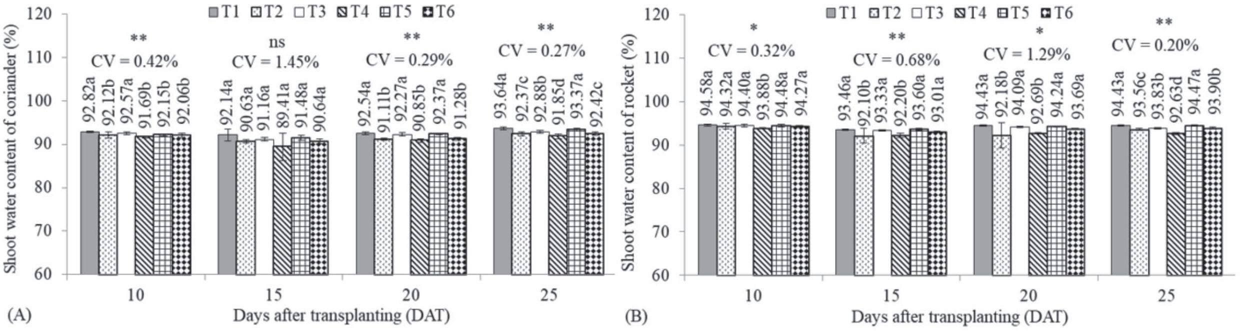
Figure 2: Mean plant height and stem diameter of coriander (A and C) and rocket (B and D) plants, respectively, under stresses of root-zone temperature and salinity and different strategies using fresh and brackish waters at 10, 15, 20 and 25 days after transplanting, in a NFT hydroponic system.

(TI-SFM) and SDM (TI-SDM) of coriander (Figures 5A and 5C) and rocket (Figures 5B and 5D) were significantly affected ($p < 0.01$) by treatments in all evaluated periods.

As expected, the combination of stress (T4) had a more negative effect on commercial production (SFM) (Figures 4A and 4B). However, for coriander this was only observed in the last evaluation (Figure 4A). In this case, up to 20 DAT the combined effect of stresses was similar to the isolated effect of salinity (T2 and T6). For rocket (Figure 4B), from 15 DAT the means of SFM obtained in T4 were always lower compared to those of the other treatments.

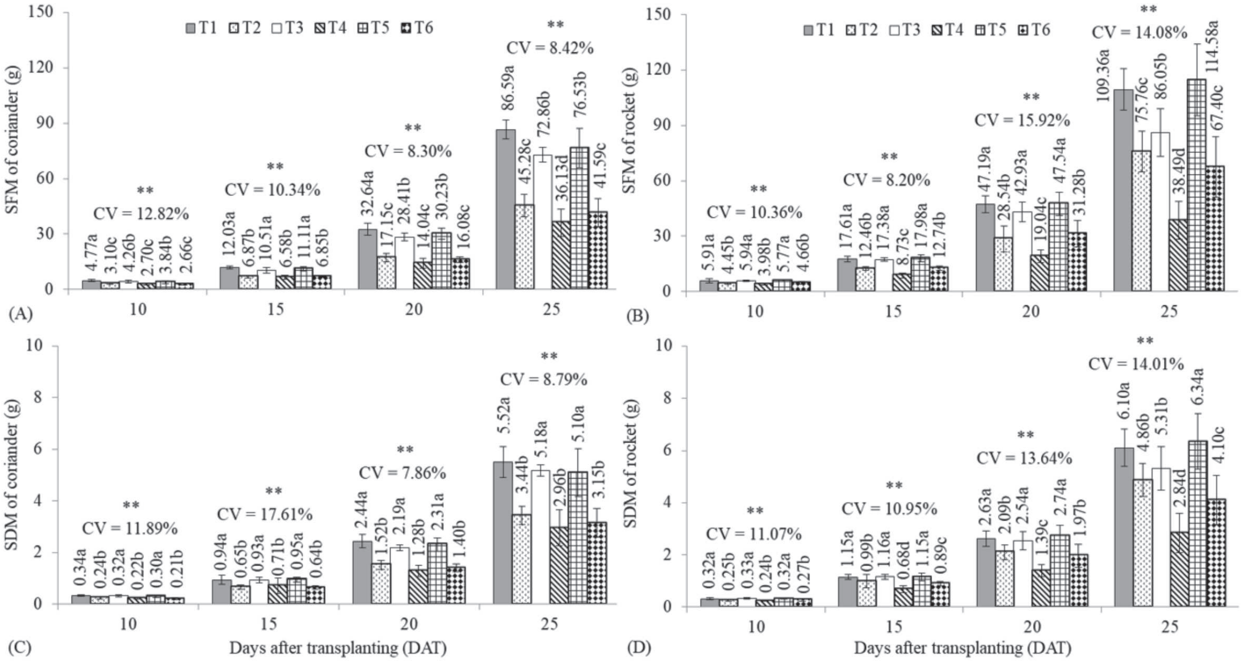
In general, for SDM of coriander (Figure 4C), the effects of the treatments were divided into two groups, with the highest means in T1, T3 and T5. For rocket (Figure 4D), the effects of the treatments on SDM followed the same trend as those observed in SFM.

The results observed in the present study reinforce those found in the literature, which show the different



Details of treatments T1, T2, T3, T4, T5 and T6 are described in the Table 1; CV - coefficient of variation; * and ** - significant at p < 0.05 and *p* < 0.01 and ns - not significant by F-test; means followed by the same letter are not significantly different at p = 0.05 by Scott-Knott test; vertical bars indicate the means ± standard deviation (n = 5).

Figure 3: Mean water content of shoot of coriander (A) and rocket (B) under stresses of root-zone temperature and salinity and different strategies using fresh and brackish waters at 10, 15, 20 and 25 days after transplanting, in a NFT hydroponic system.



Details of treatments T1, T2, T3, T4, T5 and T6 are described in the Table 1; CV - coefficient of variation; ** - significant at p < 0.01 by F-test; means followed by the same letter are not significantly different at p = 0.05 by Scott-Knott test; vertical bars indicate the means ± standard deviation (n = 5).

Figure 4: Mean fresh matter - SFM and dry matter of shoot - SDM of coriander (A and C) and rocket (B and D) plants, respectively, under stresses of root-zone temperature and salinity and different strategies using fresh and brackish waters at 10, 15, 20 and 25 days after transplanting, in a NFT hydroponic system.

impacts of abiotic stresses on crops (Incrocci *et al*., 2019; Ashraf *et al*., 2020) and according to the stage of development (Ahmadi & Souri, 2018; Bulgari *et al*., 2019). Under saline conditions, in the short term, the reduction of plant growth is an immediate effect caused by the osmotic component, resulting from the high concentration of solutes in the root zone (Carillo *et al*., 2019), which reduces cell expansion (Bekhradi *et al*., 2015; Franzoni *et al*., 2020).

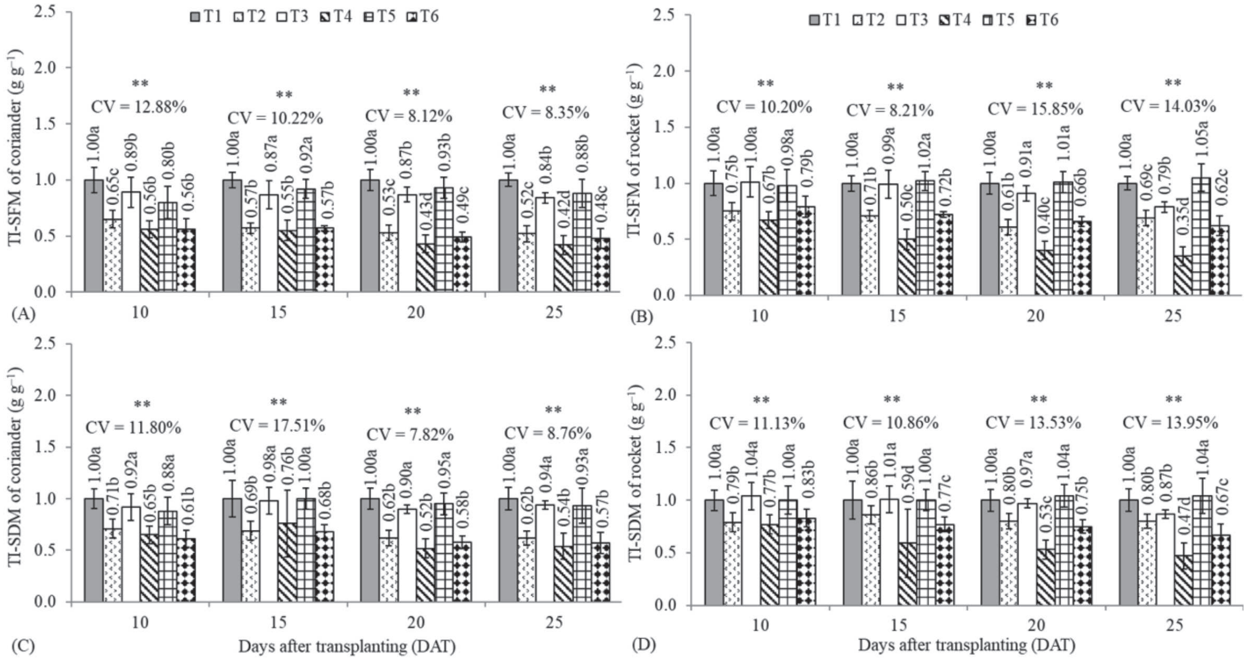
In the present study, under the combination of stresses (T4), the SFM production of coriander was 36.13 g (bunch of 12 plants) at 25 DAT (Figure 4A). In the study conducted by Silva *et al*. (2020a), the SFM for the same coriander cultivar was of same magnitude (34.16 g for a bunch of 12 plants) also under the combination of salt stress (ECw of 6.5 dS m^{-1}) and constant RZT of 30 ºC, in NFT hydroponics for 25 DAT.

Under T2 and T6 (statistically similar), the reduction in coriander SFM at 25 DAT was approximately 50% compared to T1 (Figure 4A). Reduction of the same magnitude has been observed in other studies with coriander grown in pots with soil, under ECw of 6.25 dS m^{-1} in comparison to ECw of 0.45 dS m^{-1} (Ghazi, 2018) and under irrigation water salinity equivalent to 75 mM NaCl in comparison to the control (0 mM NaCl) (Al-Garni *et al*., 2019). In the study conducted by Elhindi *et al*. (2016), the reduction was approximately 28% under irrigation water salinity corresponding to 80 mM NaCl compared to the control (0 mM NaCl).

For rocket (Figure 4B), the SFM production obtained at 25 DAT was compatible with that observed by Jesus *et al*. (2015), approximately 37 g (bunch of 10 plants) under ECw of 6.5 dS m^{-1} (under exclusive use of brackish water) at 25 DAT in NFT hydroponics.

The reduction in rocket SFM at 25 DAT under T2 and T6 compared to T1 and T5 was approximately 36% (Figure 4B). Reduction of the same magnitude in rocket SFM was observed by Silva *et al*. (2013) under ECsol of 8.5 dS m^{-1} (with NaCl) compared to the ECsol of 1.8 dS m^{-1} (without NaCl), in NFT hydroponics for 30 DAT.

Oliveira *et al*. (2018) and Cordeiro *et al*. (2019) verified reductions in SFM of rocket as a function of salinity. In the first study, the reduction was approximately 64% under ECsol of 7.3 dS m^{-1} (with NaCl, EC ~ 5.2 dS m^{-1}) compared to the ECsol of 2.1 dS m^{-1} (without NaCl). For the second study, the reduction was approximately 42% under ECsol of 5.1 dS m^{-1} (with NaCl) compared to the ECsol of 2.3 dS m^{-1} (without NaCl). In these studies, the cultivation was performed in coconut fiber substrate for 40 and 37 days, respectively.



Details of treatments T1, T2, T3, T4, T5 and T6 are described in the Table 1; CV - coefficient of variation; ** - significant at $p < 0.01$ by F-test; means followed by the same letter are not significantly different at $p = 0.05$ by Scott-Knott test; vertical bars indicate the means ± standard deviation (n = 5).

Figure 5: Mean tolerance index of the fresh matter - TI-SFM and dry matter - TI-SDM of shoot of coriander (A and C) and rocket (B and D) plants, respectively, under stresses of root-zone temperature and salinity and different strategies using fresh and brackish waters at 10, 15, 20 and 25 days after transplanting, in a NFT hydroponic system.

In summary, different responses of coriander and rocket to salt stress can be related to growing season, level of salinity used, type of stress applied and cultivation method. Additionally, the response of the species to salt stress depends on the type of salts to which they are subjected (Kurunc *et al*., 2020). As an example, in the study of Ahmadi & Souri (2018) with coriander irrigated using saline water and different salt mixtures, there was a reduction of approximately 35% in SFM under ECw of 4.0 dS m^{-1} (with NaCl) compared to the same level of ECw with mixture of KCl + NaCl + $CaCl_2$.

The results of the present study show that the effect of salt stress provoked by ECw of 6.5 dS m^{-1} was more pronounced than that of heat stress, when these were evaluated separately. Regarding the heat stress, SFM values were approximately 16% lower for coriander (Figure 4A) and 21% lower for rocket (Figure 4B) under constant RZT at 30 ºC (T3) compared to control (T1). Reduction in coriander SFM of the same magnitude was verified by Nguyen *et al*. (2020), of approximately 15% under RZT at 30 ºC in the last six days of the cycle compared to the control condition (RZT at 25 ºC along the entire 18-day cycle).

The effect of RZT varies within the same species, as observed by Silva *et al*. (2020a). These authors verified a reduction in SFM (at 25 DAT) for the same coriander cultivar used in the present study of approximately 37% under constant RZT at 32 ºC compared to ambient RZT, while for cultivar Tabocas there was no significant difference between the means as a function of RZT.

Regarding the strategies for the use of brackish water under ambient RZT, the use of fresh water to replenish the water consumed (T6) of coriander (Figure 4A) and rocket (Figure 4B) plants did not bring any gain in fresh biomass production, compared to the exclusive use of brackish water (T2). In this case, among the strategies used, it is preferable to use fresh water to prepare the solution and brackish water to replenish water consumed (T5).

Regarding the tolerance index (TI), for coriander the values based on SFM (Figure 5A) and SDM (Figure 5C) were above 0.5, except for the cultivation under combined stresses (T4) at 20 and 25 DAT, when the recorded values of TI-SFM were around 0.4. Similar results were observed for rocket (Figure 5B); however, the lowest value of TI-SFM (0.35) was recorded at 25 DAT. Behavior similar to that recorded for TI-SFM was also observed for TI-SDM for both coriander (Figure 5C) and rocket (Figure 5D), with the lowest TI values around 0.5.

When the plants were subjected to stresses of root-zone temperature and salinity for more time, there were greater reductions in TI, and the effects were more pronounced on SFM of coriander (Figure 5A) and rocket (Figure 5B). In other words, this index concerns the relative reduction in yield compared to T1. In another study with coriander, Sá *et al*. (2016) reported salinity TI for SDM of 0.32 and 0.53 for two cultivars when irrigated with saline water of ECw of 3.0 dS m^{-1} compared to the ECw of 0.3 dS m^{-1}.

CONCLUSIONS

In NFT hydroponic cultivation, the effect of heat stress (root-zone temperature of 30 °C) was mild compared to salt stress (ECw of 6.5 dS m^{-1}), especially for coriander. When these stresses were combined, the negative effect was clearly greater in rocket.

Despite the reduced fresh matter yields obtained under the combination of salt and heat stress caused by root-zone temperature of 30 ºC, the visual quality of the plants produced remained within the commercial standards.

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REFERENCES

Ahmadi M & Souri MK (2018) Growth and mineral content of coriander (*Coriandrum sativum* L.) plants under mild salinity with different salts. Acta Physiologiae Plantarum, 40:194.

Al-Garni SMS, Khan MMA & Bahieldin A (2019) Plant growth-promoting bacteria and silicon fertilizer enhance plant growth and salinity tolerance in *Coriandrum sativum*. Journal of Plant Interactions, 14:386-396.

Alisofi S, Einali A & Sangtarash MH (2019) Jasmonic acid-induced metabolic responses in bitter melon (*Momordica charantia*) seedlings under salt stress. The Journal of Horticultural Science and Biotechnology, 95:247-259.

Alves LS, Silva MG, Gheyi HR, Paz VPS, Soares TM & Rafael MRS (2019) Uso de águas salobras no cultivo da chicória em condições hidropônicas. Irriga, 24:758-769.

Ashraf MY, Tariq S, Saleem M, Khan MA, Hassan SWU & Sadef Y (2020) Calcium and zinc mediated growth and physio-biochemical changes in mungbean grown under saline conditions. Journal of Plant Nutrition, 43:512-525.

Atzori G, Mancuso S & Masi E (2019) Seawater potential use in soilless culture: A review. Scientia Horticulturae, 249:199-207.

Azizi S, Tabari M & Striker GG (2017) Growth, physiology, and leaf ion concentration responses to long-term flooding with fresh or saline water of *Populus euphratica*. South African Journal of Botany, 108:229-236.

Bekhradi F, Delshad M, Marín A, Luna MC, Garrido Y, Kashi A, Babalar M & Gil MI (2015) Effects of salt stress on physiological and postharvest quality characteristics of different Iranian genotypes of basil. Horticulture, Environment, and Biotechnology, 56:777-785.

Bione MAA, Soares TM, Cova AMW, Paz VPS, Gheyi HR, Rafael MRS, Modesto FJN, Santana JA & Neves BSL (2021) Hydroponic production of 'Biquinho' pepper with brackish water. Agricultural Water Management, 245:106607.

Bonasia A, Lazzizera C, Elia A & Conversa G (2017) Nutritional, biophysical and physiological characteristics of wild rocket genotypes as affected by soilless cultivation system, salinity level of nutrient solution and growing period. Frontiers in Plant Science, 8:300.

Bulgari R, Franzoni G & Ferrante A (2019) Biostimulants application in horticultural crops under abiotic stress conditions. Agronomy, 9:306.

Campos Júnior JE, Santos Júnior JA, Martins JB, Silva EFF & Almeida CDGC (2018) Rocket production in a low cost hydroponic system using brackish water. Revista Caatinga, 31:1008-1016.

Carillo P, Raimondi G, Kyriacou MC, Pannico A, El-Nakhel C, Cirillo V, Colla G, De Pascale S & Rouphael Y (2019) Morpho-physiological and homeostatic adaptive responses triggered by omeprazole enhance lettuce tolerance to salt stress. Scientia Horticulturae, 249:22-30.

Cocetta G, Mishra S, Raffaelli A & Ferrante A (2018) Effect of heat root stress and high salinity on glucosinolates metabolism in wild rocket. Journal of Plant Physiology, 231:261-270.

Cordeiro CJX, Leite Neto JS, Oliveira MKT, Alves FAT, Miranda FAC & Oliveira FA (2019) Cultivo de rúcula em fibra de coco utilizando solução nutritiva salinizada enriquecida com nitrato de potássio. Revista Brasileira de Agricultura Irrigada, 13:3212-3225.

Costa LD, Tomasi N, Gottardi S, Iacuzzo F, Cortella G, Manzocco L, Pinton R, Mimmo T & Cesco S (2011) The effect of growth medium temperature on corn salad [*Valerianella locusta* (L.) Laterr] baby leaf yield and quality. HortScience, 46:1619-1625.

D'Imperio M, Montesano FF, Renna M, Leoni B, Buttaro D, Parente A & Serio F (2018) NaCl stress enhances silicon tissue enrichment of hydroponic "baby leaf" chicory under biofortification process. Scientia Horticulturae, 235:258-263.

D'Imperio M, Renna M, Cardinali A, Buttaro D, Serio F & Santamaria P (2016) Calcium biofortification and bioaccessibility in soilless "baby leaf" vegetable production. Food Chemistry, 213:149-156.

Elhindi KM, El-Hendawy S, Abdel-Salam S, Schmidhalter U, Rehman S-U & Hassan A-A (2016) Foliar application of potassium nitrate affects the growth and photosynthesis in coriander (*Coriander sativum* L.) plants under salinity. Progress in Nutrition, 18:63-73.

Franzoni G, Cocetta G, Trivellini A & Ferrante A (2020) Transcriptional regulation in rocket leaves as affected by salinity. Plants, 9:20.

Freitas WES, Oliveira AB, Mesquita RO, Carvalho HH, Prisco JT & Gomes-Filho E (2019) Sulfur-induced salinity tolerance in lettuce is due to a better P and K uptake, lower Na/K ratio and an efficient antioxidative defense system. Scientia Horticulturae, 257:108764.

Furlani PR, Silveira LCP, Bolonhezi D & Faquin V (1999) Cultivo hidropônico de plantas. Instituto Agronômico, Campinas. 52 p. (Boletim Técnico, 180).

Ghazi DA (2018) The contribution of nano-selenium in alleviation of salinity adverse effects on coriander plants. Journal of Soil Sciences and Agricultural Engineering, 9:753-760.

He J, See XE, Qin L & Choong TW (2016) Effects of root-zone temperature on photosynthesis, productivity and nutritional quality of aeroponically grown salad rocket (*Eruca sativa*) vegetable. American Journal of Plant Sciences, 7:1993-2005.

Incrocci L, Marzialetti P, Incrocci G, Di Vita A, Balendonck J, Bibbiani C & Pardossi A (2019) Sensor-based management of container nursery crops irrigated with fresh or saline water. Agricultural Water Management, 213:49-61.

Ito A, Shimizu H, Hiroki R, Nakashima H, Miyasaka J & Ohdoi K (2013) Effect of different durations of root area chilling on the nutritional quality of spinach. Environmental Control in Biology, 51:187-191.

Jesus CG, Silva Júnior FJ, Camara TR, Silva EFF & Willadino L (2015) Production of rocket under salt stress in hydroponic systems. Horticultura Brasileira, 33:493-497.

Kitayama M, Samphumphuang T, Tisarum R, Theerawitaya C, Cha-um K, Takagaki M & Cha-um S (2020) Calcium and soluble sugar enrichments and physiological adaptation to mild NaCl salt stress in sweet potato (*Ipomoea batatas*) genotypes. The Journal of Horticultural Science and Biotechnology, 95:782-793.

Kurunc A, Aslan GE, Karaca C, Tezcan A, Turgut K, Karhan M & Kaplan B (2020) Effects of salt source and irrigation water salinity on growth, yield and quality parameters of *Stevia rebaudiana* Bertoni. Scientia Horticulturae, 270:109458.

Li J, Gao Y, Zhang X, Tian P, Li J & Tian Y (2019) Comprehensive comparison of different saline water irrigation strategies for tomato production: Soil properties, plant growth, fruit yield and fruit quality. Agricultural Water Management, 213:521-533.

Martins JB, Santos Júnior JA, Bartusch VP, Gheyi HR, Bezerra Neto E & Silva MM (2019) Water relations in parsley plants cultivated in brackish nutrient solutions of different cationic natures. Revista Brasileira de Engenharia Agrícola e Ambiental, 23:662-668.

Mehrabani LV, Kamran RV, Khurizadeh S & Nezami SS (2018) Response of coriander to salinity stress. Journal of Plant Physiology and Breeding, 8:89-98.

Negrão S, Schmöckel SM & Tester M (2017) Evaluating physiological responses of plants to salinity stress. Annals of Botany, 119:01-11.

Nguyen DTP, Lu N, Kagawa N, Kitayama M & Takagaki M (2020) Short-term root-zone temperature treatment enhanced the accumulation of secondary metabolites of hydroponic coriander (*Coriandrum sativum* L.) grown in a plant factory. Agronomy, 10:413.

Nguyen DTP, Lu N, Kagawa N & Takagaki M (2019) Optimization of photosynthetic photon flux density and root-zone temperature for enhancing secondary metabolite accumulation and production of coriander in plant factory. Agronomy, 9:224.

Oliveira FA, Leite Neto JS, Oliveira MKT, Lima LA, Nascimento LV, Cordeiro CJX, Alves FAT, Miranda FAC & Morais Neta HM (2018) Response of arucula cultivars to saline nutritive solution enriched with potassium nitrate. Journal of Agricultural Science, 10:269-279.

Sá FVS, Souto LS, Paiva EP, Ferreira Neto M, Silva RA, Silva MKN, Mesquita EF, Almeida FA & Alves Neto A (2016) Tolerance of coriander cultivars under saline stress. African Journal of Agricultural Research, 11:3728-3732.

Sakamoto M & Suzuki T (2015) Effect of root-zone temperature on growth and quality of hydroponically grown red leaf lettuce (*Lactuca sativa* L. cv. Red Wave). American Journal of Plant Sciences, 6:2350-2360.

Sakamoto M, Uenishi M, Miyamoto K & Suzuki T (2016) Effect of root-zone temperature on the growth and fruit quality of hydroponically grown strawberry plants. Journal of Agricultural Science, 8:122-131.

Santos JF, Coelho Filho MA, Cruz JL, Soares TM & Cruz AML (2019) Growth, water consumption and basil production in the hydroponic system under salinity. Revista Ceres, 66:45-53.

Shaukat M, Wu J, Fan M, Hussain S, Yao J & Serafim ME (2019) Acclimation improves salinity tolerance capacity of pea by modulating potassium ions sequestration. Scientia Horticulturae, 254:193-198.

Silva FV, Duarte SN, Lima CJGS, Dias NS, Santos RSS & Medeiros PRF (2013) Cultivo hidropônico de rúcula utilizando solução nutritiva salina. Revista Brasileira de Ciências Agrárias, 8:476-482.

Silva MG, Alves LS, Soares TM, Gheyi HR & Bione MAA (2020b) Growth, production and water use efficiency of chicory (*Cichorium endivia* L.) in hydroponic systems using brackish waters. Advances in Horticultural Science, 34:243-253.

Silva MG, Oliveira IS, Soares TM, Gheyi HR, Santana GO & Pinho JS (2018) Growth, production and water consumption of coriander in hydroponic system using brackish waters. Revista Brasileira de Engenharia Agrícola e Ambiental, 22:547-552.

Silva MG, Soares TM, Gheyi HR, Costa IP & Vasconcelos RS (2020c) Growth, production and water consumption of coriander grown under different recirculation intervals and nutrient solution depths in hydroponic channels. Emirates Journal of Food and Agriculture, 32:281-294.

Silva MG, Soares TM, Gheyi HR, Oliveira IS & Silva Filho JA (2016c) Crescimento e produção de coentro hidropônico sob diferentes densidades de semeadura e diâmetros dos canais de cultivo. Irriga, 21:312-326.

Silva MG, Soares TM, Gheyi HR, Oliveira IS, Silva Filho JA & Carmo FF (2016a) Frequency of recirculation of the nutrient solution in the hydroponic cultivation of coriander with brackish water. Revista Brasileira de Engenharia Agrícola e Ambiental, 20:447-454.

Silva MG, Soares TM, Gheyi HR, Oliveira MGB & Santos CC (2020a). Hydroponic cultivation of coriander using fresh and brackish waters with different temperatures of the nutrient solution. Engenharia Agrícola, 40:674-683.

Silva MG, Soares TM, Oliveira IS, Santos JCS, Pinho JS & Freitas FTO (2015) Produção de coentro em hidroponia NFT com o uso de águas salobras para reposição do consumo evapotranspirado. Revista Brasileira de Agricultura Irrigada, 9:246-258.

Silva S, Nascimento R, Oliveira H, Cardoso JAF, Xavier DA & Silva SS (2016b) Levels of nitrate, pigments and thermographic analysis of lettuce under different temperatures of nutrient solution. African Journal of Agricultural Research, 11:1668-1673.

Silva Júnior FJ, Santos Júnior JA, Silva MM, Silva EFF & Souza ER (2019) Water relations of chives in function of salinity and circulation frequency of nutrient solutions. Revista Brasileira de Engenharia Agrícola e Ambiental, 23:359-365.

Soares HR, Silva EFF, Silva GF, Pedrosa EMR, Rolim MM & Santos AN (2015) Lettuce growth and water consumption in NFT hydroponic system using brackish water. Revista Brasileira de Engenharia Agrícola e Ambiental, 19:636-642.

Souza MCG, Morais MB, Andrade MS, Vasconcelos MA, Sampaio SS & Albuquerque CC (2020) Mycorrhization and saline stress response in *Hyptis suaveolens*. Ciência Rural, 50:e20190533.

Sun J, Lu N, Xu H, Maruo T & Guo S (2016) Root zone cooling and exogenous spermidine root-pretreatment promoting *Lactuca sativa* L. growth and photosynthesis in the high-temperature season. Frontiers in Plant Science, 7:368.