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## HYDROPONIC CULTIVATION OF CORIANDER USING FRESH AND BRACKISH WATERS WITH DIFFERENT TEMPERATURES OF THE NUTRIENT SOLUTION

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### KEYWORDS

*Coriandrum sativum* L., abiotic stress, shoot fresh matter, hydroponics, salinity.

### ABSTRACT

A large number of studies on salinity in hydroponic systems have been carried out, but few of them have evaluated the interaction between salinity and nutrient solution temperatures. Two experiments were carried out in a randomized block design from January to February (Experiment I) and June to July 2018 (Experiment II). Experiment I consisted of treatments with five combinations, as follows: unheated (control) and heated nutrient solution (NS) at a temperature of 32°C using fresh water with an electrical conductivity (EC<sub>w</sub>) of 0.3 dS m<sup>-1</sup>, and unheated and heated NS at temperatures of 30 and 32°C using brackish water with an EC<sub>w</sub> of 6.5 dS m<sup>-1</sup> in the main plots, with two coriander cultivars (Tabocas and Verdão) in the subplots, which were grown in the same hydroponic channel. The cultivar Verdão was grown in Experiment II in a 2 × 2 factorial arrangement, consisting of two NS temperatures (unheated and heated at 30°C) and two EC<sub>w</sub> levels (0.3 and 6.5 dS m<sup>-1</sup>). Coriander cultivation is feasible with heated NS despite decreases in shoot fresh matter production compared to the control of approximately 37% for Experiment I (cultivar Verdão at a temperature of 32°C and using fresh water) and 17% for Experiment II (temperature of 30°C and using fresh and brackish waters) at 25 days after transplanting.

### INTRODUCTION

Coriander (*Coriandrum sativum* L.) is one of the spices that occupy a prominent position worldwide, adding flavor and aroma to several foods (Rashed & Darwesh, 2015). In addition to its use in cooking, coriander is used in the food and pharmaceutical industries due to its medicinal properties (Uitterhaegen et al., 2018).

In Brazil, especially in the Northeast region, coriander is grown by small and medium producers aiming at green matter production, including the cultivation under hydroponic systems in some states of this region (Albuquerque & Mesquita, 2016). The low availability of surface waters in this region has led to the use of underground water sources, which are usually extracted from wells and have high salt concentrations (Silva et al., 2018a), limiting their use for conventional irrigation due to soil salinization problems and even desertification (Endo et al., 2011; Suassuna et al., 2017).

Plants under natural conditions undergo different abiotic stresses (Xu et al., 2018), such as salinity, water deficit, temperature, and others (Szareski et al., 2018). Salt stress affects plant growth due to the negative effect of the osmotic potential on water absorption, resulting in changes in water relations at the cellular level (García-Caparrós & Lao, 2018) and excessive accumulation of ions (Na<sup>+</sup> and/or Cl<sup>-</sup>) in plants (Rady et al., 2018).

Cultivation of plants in nutrient solutions without the use of soil has been a technically feasible solution to mitigate the problem of using brackish waters due to high water availability to plants and the absence of water retention forces by the soil matrix (Tavakkoli et al., 2010; Silva et al., 2020a). Thus, the sustainable use of brackish waters is expected in hydroponic systems with short cycle crops (Lira et al., 2018; Alves et al., 2019).

Lettuce is one of the main crops used in studies carried out with brackish waters in hydroponic systems

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(Al-Maskri et al., 2010; Soares et al., 2015; Cova et al., 2017; Niu et al., 2018; Silva et al., 2018b). The results of these studies enabled crop diversification, including coriander (Cazuza Neto et al., 2014; Silva et al., 2015; Silva et al., 2016a; Silva et al., 2018a). Most of these studies have shown reductions in plant growth because of the salt stress, but without considering the effects of the interaction between the temperature of the nutrient solution and water salinity. The dynamics of this interaction are important for plant production under hydroponic conditions using brackish water, especially in arid and semiarid tropical regions, which have high temperatures for most of the year, as the semi-arid region in the Northeast of Brazil.

Therefore, this study aimed to evaluate the growth, production, and quality of coriander plants using nutrient solutions prepared from fresh and brackish waters at different temperatures.

## MATERIAL AND METHODS

Two experiments with coriander (*Coriandrum sativum* L.) under hydroponic conditions were carried out in a greenhouse (East-West orientation with uncontrolled environment), one from January to February (summer, Experiment I) and other from June to July 2018 (autumn-winter, Experiment II). The greenhouse was 7.0 m wide and 24.0 m long, with ceiling height of 2.8 m, protected on the sides by black shade screen and covered by 150- $\mu$ m-thick polyethylene film. The study site was in the experimental area of the Post Graduate Program in Agricultural Engineering, at the Soil and Water Engineering Nucleus, belonging to the Federal University of Recôncavo of Bahia, located in the municipality of Cruz das Almas, Bahia State, Brazil (12° 40' 19" S, 39° 06' 23" W, and at an altitude of 220 m above mean sea level).

The experiments were carried out in a randomized block design, with five replicates. Experiment I consisted of treatments with five combinations, as follows: unheated (control) and heated nutrient solution (NS) at a temperature of 32°C prepared in fresh water with an electrical conductivity (EC<sub>w</sub>) of 0.3 dS m<sup>-1</sup>, and unheated and heated NS at temperatures of 30 and 32°C using brackish water with an EC<sub>w</sub> of 6.5 dS m<sup>-1</sup> in the main plots, with two coriander cultivars (Tabocas and Verdão) in the subplots, which were grown in the same hydroponic channel. Cultivar Verdão was grown in Experiment II in a 2 × 2 factorial arrangement without adopting the coriander cultivars in the subplots and consisting of two NS temperatures (unheated and heated at 30°C) and two EC<sub>w</sub> levels (0.3 and 6.5 dS m<sup>-1</sup>). These waters were used to prepare the nutrient solutions and to replace the volume consumed by the plants in both experiments during the cultivation period.

Nutrient solution temperatures above 30°C under hydroponic conditions have been reported as not adequate for the growth of various plant species. Thus, temperatures equal to and higher than this temperature limit were used in the present study, as used in other studies (Nxawe et al., 2011; Sakamoto & Suzuki, 2015; Sakamoto et al., 2016), also with constant temperatures during the cultivation.

The experiments were conducted using a nutrient film technique (NFT) hydroponic system with 6-m long channels made of PVC pipes of 0.075 m in diameter and a 3.0% slope containing circular holes with 0.05 m in diameter

spaced at 0.25 m. Benches with trestles made of PVC pipes of 0.05 m in diameter were used to support the hydroponic channels (1.10 m in height from the soil surface). Four hydroponic channels were used per bench, with a horizontal spacing of 0.25 m. A spacing of 0.50 m was left between the benches to facilitate transit and operability.

Each treatment consisted of a 500-L capacity plastic tank for storing the nutrient solution and an electric pump (32 W) to inject the solution into five hydroponic channels simultaneously. The tank had a ballcock valve to maintain a constant volume of 400 L of the nutrient solution from the water supply tank, built with PVC pipes of 0.15 m in diameter, similar to that adopted by Silva et al. (2020b).

Nutrient solution temperatures were maintained constant at 30 and 32°C using a heating element (2000 W). For this, each plastic tank had a DS18B20 temperature sensor for continuous monitoring of the nutrient solution temperatures. The heating control system was developed using an Arduino Uno microcontroller. In addition to the temperature sensor, the following electronic components were connected to the microcontroller: a real-time clock (RTC) module, with date, time, and calendar functions; an SD card reader module, used for data logging; and a relay module, used to control the heaters.

Seeds of two coriander cultivars (Tabocas and Verdão), and only the cultivar Verdão were sown in 80-mL plastic cups containing coconut fiber substrate on January 19 and June 1, 2018, for Experiments I and II, respectively. Fifteen seeds of each coriander cultivar were sown per cup filled with the substrate to the top. The bottom of the cup had holes for the roots to grow. The seedlings were manually irrigated until transplanting to the hydroponic channels using public-supply water (EC<sub>w</sub> of 0.3 dS m<sup>-1</sup>).

Coriander seedlings were transplanted to the hydroponic channels at 13 and 10 days after sowing for Experiments I and II, respectively, when treatments started. Thinning was carried out before transplanting aiming to maintain 12 seedlings per cup, according to recommendations of Silva et al. (2016b). Each hydroponic channel had 20 coriander bunches (10 of the cultivar Tabocas and 10 of the cultivar Verdão) for Experiment I and 10 bunches of the cultivar Verdão for Experiment II. The heating of the nutrient solutions for the treatments started one day before transplanting at temperatures of 30 and 32°C for Experiment I and 30°C for Experiment II.

The brackish water (EC<sub>w</sub> of 6.5 dS m<sup>-1</sup>) was prepared by adding sodium chloride (NaCl) to public-supply water (EC<sub>w</sub> of 0.3 dS m<sup>-1</sup>). Subsequently, fertilizer salts were added using as reference the standard nutrient solution recommended by Furlani et al. (1999) for leafy vegetables. After adding the nutrients, the resulting electrical conductivities of the nutrient solutions (EC<sub>sol</sub>) were 2.7 and 8.5 dS m<sup>-1</sup> for Experiment I and 2.5 and 8.9 dS m<sup>-1</sup> for Experiment II, with automatic temperature compensation at 25°C and pH values of approximately 6.0. The pH of the nutrient solutions in the tanks was evaluated during the experiments using a pH meter with a precision of 0.01, with automatic temperature compensation (Hanna Instruments Inc., Woonsocket, Rhode Island, USA). The pH values oscillated within the range recommended for hydroponic cultivation, 5.4 to 6.5 for Experiment I and 5.8 to 6.5 for Experiment II.

At the end of the experiments, the ECsol values with automatic temperature compensation at 25°C were 2.60 and 2.65 dS m<sup>-1</sup> under unheated and heated nutrient solutions, with a temperature at 32°C using fresh water, and 10.06, 10.10, and 10.12 dS m<sup>-1</sup> under unheated and heated nutrient solutions, with temperatures at 30 and 32°C, respectively, using brackish water in Experiment I. In Experiment II, the ECsol values were 1.92 and 2.77 dS m<sup>-1</sup> using fresh water and 9.75 and 11.10 dS m<sup>-1</sup> using brackish water under unheated and heated nutrient solutions (temperature at 30°C), respectively. The ECsol values were measured using a CS547A probe (Campbell Scientific, Inc., Logan, Utah, USA).

For nutrient solution circulations in the hydroponic channels, in Experiment I the control of the electric pumps activation was performed on the Arduino Uno microcontroller, as described above, with irrigations programmed in alternating intervals of 10 min (turned on for 10 min and turned off for 10 min). In Experiment II, the irrigations were every 15 min using an analog timer.

The visual aspect of the coriander was monitored periodically to identify any symptoms related to mineral deficiency/toxicity, as well as damage caused by pest and diseases.

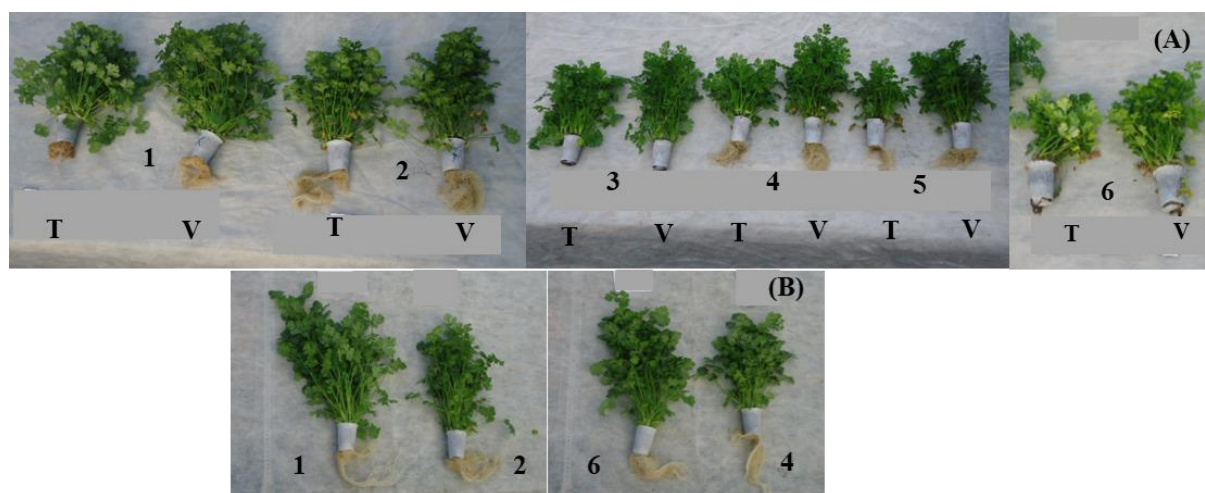
Harvests were performed at 10, 15, 20, and 25 days after transplanting (DAT). Two bunches of each coriander cultivar containing 12 plants were collected in each harvest from each plot in Experiments I and II, to determine the stem diameter (SD), plant height (PH), and shoot fresh matter (SFM). The SD was measured in three plants of each bunch at a height of 3 cm above the substrate level using a digital caliper. The PH was measured using a

measuring tape from the point of cut (substrate) up to the plant apex. The fresh plants were placed in paper bags immediately after weighing and dried in a forced-air ventilation oven at a temperature of 65°C until constant weight to quantify the shoot dry matter (SDM).

The data were subjected to analysis of variance by the F-test and the means were compared by the Tukey test at a 0.05 probability level. The standard deviations of the means were also calculated.

## RESULTS AND DISCUSSION

Fig. 1A (Experiment I) and Fig. 1B (Experiment II) show the coriander plants produced under different cultivation conditions (fresh and brackish waters under interaction with temperatures of the nutrient solutions) in the last evaluated period, at 25 DAT. Experiment I, carried out in the summer season, showed that plants of both coriander cultivars presented visual symptoms of burning at the edges of the older leaves (resulting in necrosis) at 6 DAT when grown using brackish water (ECw of 6.5 dS m<sup>-1</sup>), regardless of the temperature of the nutrient solution. The number of symptomatic leaves was the same until the end of the experiment, and new leaves showed no abnormalities after the first recorded symptoms. The plants probably underwent an osmotic shock after transplanting to the hydroponic system under salt stress since they were transplanted to a new environment, showing notably disturbances related to the growth medium. According to Shavrukov (2013) and Lakra et al. (2019), osmotic shock occurs when plants are suddenly exposed to salinity.



T – cultivar Tabocas; V – cultivar Verdão; 1, 3 and 6 – plants grown under unheated and heated nutrient solutions, with temperatures at 32 and 30°C, respectively, using fresh water; 2, 4 and 5 – plants grown under unheated and heated nutrient solutions, with temperatures at 30 and 32°C, respectively, using brackish water.

FIGURE 1. Visual aspect of coriander plants under different cultivation conditions using fresh and brackish waters under interaction with temperatures of the nutrient solutions, in a NFT hydroponic system for Experiments I (A) and II (B).

Salt stress in coriander plants was more significant in the warmer season (Fig. 1A). No visual symptoms were found in the plant shoot or roots due to the salt and thermal stress in Experiment II (Fig. 1B). Silva et al. (2018a) found no disturbances in coriander cultivar Verdão grown in the DFT hydroponic system in the winter, even under a water salinity of 7.0 dS m<sup>-1</sup>. It shows the importance of studies under contrasting climate conditions and different cultivars of the same species.

In Experiment I (Fig. 1A), coriander plants grown with fresh water (ECw of 0.3 dS m<sup>-1</sup>) and unheated and heated nutrient solution at a temperature of 32°C showed visual anomalies in the roots, especially those of the cultivar Tabocas, showing less development and dark color. These symptoms were related to the presence of *Pythium* sp., whose growth is favored by high temperatures and low oxygenation conditions, causing stress in plants and reducing their natural resistance. The

plant shoot was not affected despite these symptoms in the roots. The experiment was carried out with six treatments in the main plots, but the roots of all plants grown with no salt stress ( $EC_w$  of  $0.3 \text{ dS m}^{-1}$ ) and nutrient solution heated at a temperature of  $30^\circ\text{C}$  were affected drastically from 20 DAT, caused by *Pythium* sp., leading to the total wilting of the shoot at the end of the experiment. Thus, this treatment was excluded.

In general, the mean daily temperatures of the nutrient solutions in the tanks continuously monitored by sensors connected to the Arduino system in the treatments using fresh and brackish waters were similar in

Experiments I (Fig. 2A) and II (Fig. 2B). The highest mean temperatures in the cultivation under unheated nutrient solutions in Experiment I were found in the first and last five days, reaching approximately  $30^\circ\text{C}$  (Fig. 2A). On the other hand, the temperatures did not exceed  $25^\circ\text{C}$  in Experiment II (Fig. 2B). The means of treatments with heated nutrient solutions at temperatures of  $30$  and  $32^\circ\text{C}$  (brackish water) and  $32^\circ\text{C}$  (fresh water) in Experiment I were  $30.38 \pm 0.27$ ,  $32.25 \pm 0.16$ , and  $32.28 \pm 0.26^\circ\text{C}$ , respectively. The means during Experiment II under heated solution at temperature of  $30^\circ\text{C}$  were  $30.17 \pm 0.32$  and  $30.35 \pm 0.24^\circ\text{C}$  using fresh and brackish waters, respectively.

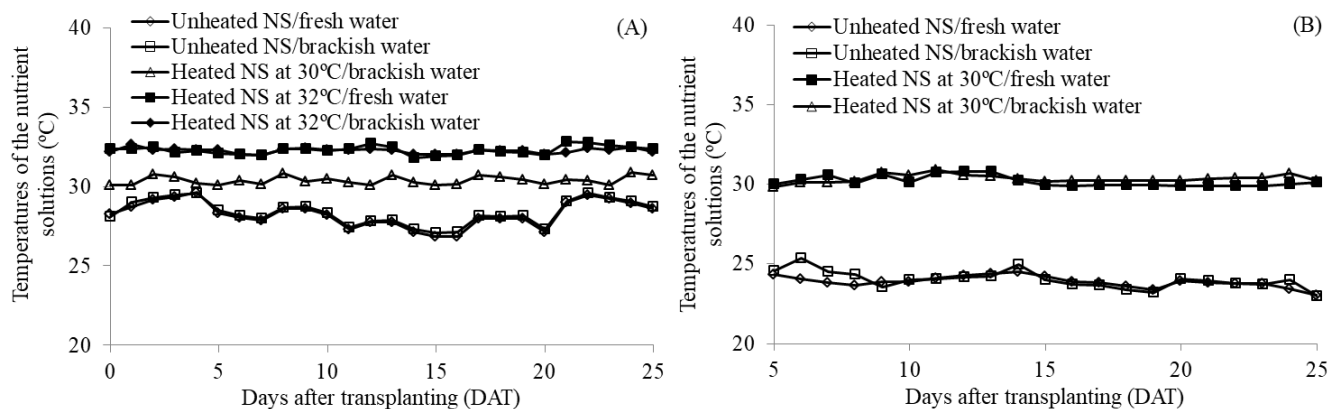


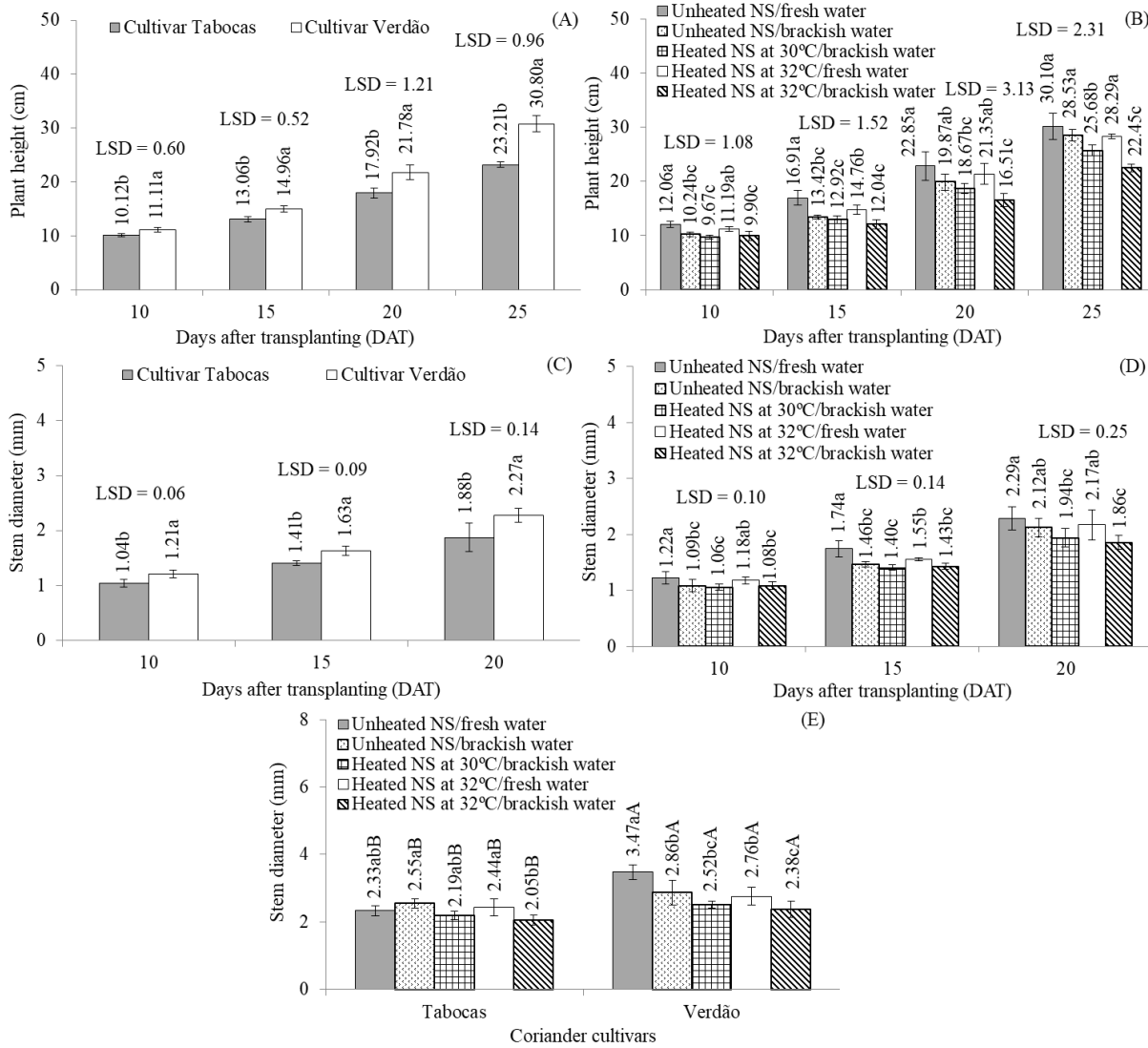
FIGURE 2. Mean daily temperatures of the nutrient solutions (NS) under different cultivation conditions using fresh and brackish waters under interaction with temperatures of the nutrient solutions, in a NFT hydroponic system for Experiments I (A) and II (B).

Plant nutrient uptake depends on the temperature of the nutrient solution because it directly affects nutrient absorption. The effect of temperature on nutrient uptake cannot be generalized, as these effects vary depending on the physiological processes and organs of plants (Yan et al., 2012), and can cause phytosanitary and nutritional problems in plants, mainly due to the low availability of oxygen to the roots (Monteiro Filho et al., 2018). According to Sakamoto et al. (2016) and Al-Rawahy et al. (2019), the dissolved oxygen concentrations has an inverse relationship with the temperatures of the nutrient solutions, that is, oxygen availability decreases in the plant rhizosphere with increasing solution temperatures, as observed in a previous experiment with coriander (Silva et al., 2020b).

Different responses have been reported for different temperatures of the nutrient solutions. In this sense, the highest lettuce productions were found under temperatures of up to  $26^\circ\text{C}$  (Cometti et al., 2013) and  $25^\circ\text{C}$  (Silva et al., 2016c), while spinach reached the highest productions of

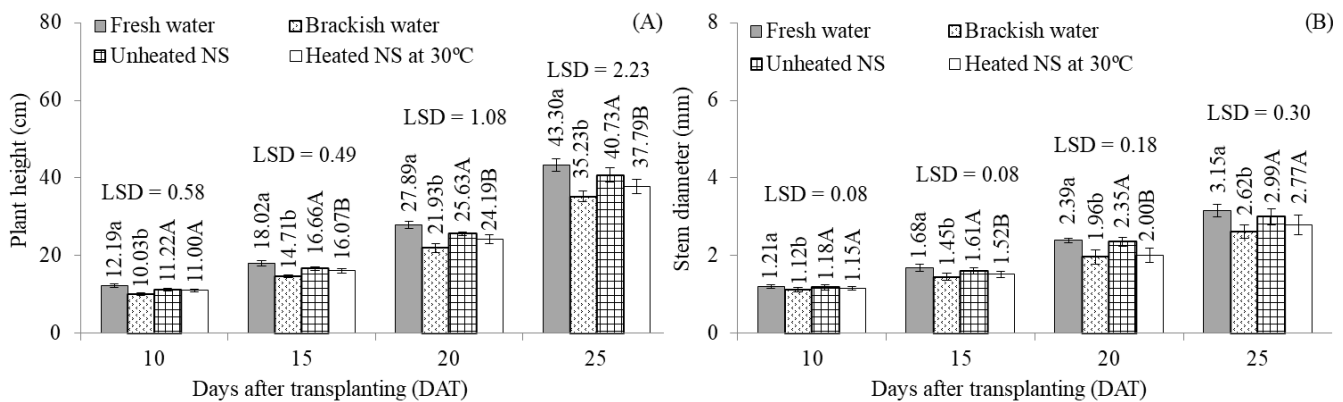
up to  $28^\circ\text{C}$  (Nxawe et al., 2009) and  $20^\circ\text{C}$  (Chadirin et al., 2012). High temperatures are registered for most of the year in the Northeast of Brazil, and the temperatures of the nutrient solutions can exceed  $30^\circ\text{C}$  during the hottest hours of the day, as observed in hydroponic crops using brackish waters, such as rocket (Silva et al., 2011) and lettuce (Silva et al., 2018b).

In general, the plant height (Fig. 3A and 3B) and stem diameter (Fig. 3C and 3D) of coriander plants in Experiment I were significantly affected by the isolated effects of the factors under study (cultivars, temperatures of nutrient solutions, and fresh and brackish waters), except for stem diameter at 25 DAT (Fig. 3E), with a significant interaction between factors. The interaction between factors in Experiment II caused no significant changes in plant height (Fig. 4A) and stem diameter (Fig. 4B), but the isolated effects of water types significantly affected these variables in the evaluated periods and temperatures of the nutrient solutions, except at 10 DAT for plant height and 10 and 25 DAT for stem diameter.



NS – nutrient solution; LSD – least significant difference; vertical bars indicate the standard deviations of the means; in Figures A-D – means followed by the same letter are not significantly different by the Tukey test at a 0.05 probability level; in Figure E – lowercase letters compare the means of the combinations (temperatures of the nutrient solutions using fresh and brackish waters) in each cultivar (with LSD = 0.36) and uppercase letters compare the means of the cultivars in each combination (with LSD = 0.25).

FIGURE 3. Mean plant height (A and B) and stem diameter (C, D and E) of coriander plants under different cultivation conditions using fresh and brackish waters under interaction with temperatures of the nutrient solutions, in a NFT hydroponic system for Experiment I.



NS – nutrient solution; LSD – least significant difference; vertical bars indicate the standard deviations of the means; lowercase letters compare the means of water types (fresh and brackish) and uppercase letters compare the means of the temperatures of the nutrient solutions for the isolated effects; means followed by the same letter are not significantly different by the Tukey test at a 0.05 probability level.

FIGURE 4. Mean plant height (A) and stem diameter (B) of coriander cultivar Verdão under different cultivation conditions using fresh and brackish waters under interaction with temperatures of the nutrient solutions, in a NFT hydroponic system for Experiment II.

In Experiment I, coriander plants of the cultivars Tabocas and Verdão presented a plant height of 4.7 and 4.8 cm and a stem diameter of 0.69 and 0.83 mm, respectively, on the day of transplanting. The plant height of the cultivar Verdão varied from 11.11 to 30.80 cm between 10 and 25 DAT, while the plant height of the cultivar Tabocas was 8.91 and 24.64% lower, respectively (Fig. 3A). The superiority in plant height of the cultivar Verdão compared to the cultivar Tabocas was reported by Bonifacio et al. (2014) for plants grown on a sand substrate irrigated at 50 and 100 mM NaCl concentrations in the nutrient solutions (ECsol of 6.5 and 12.3 dS m<sup>-1</sup>, respectively) at 30 days.

The combinations between the temperatures of the nutrient solutions and water types (Fig. 3B) showed that the highest means of plant height were observed, in general, in plants grown using fresh water, regardless of the temperatures of the nutrient solutions. The highest plant heights were also obtained at 20 and 25 DAT using brackish water only under the unheated nutrient solution.

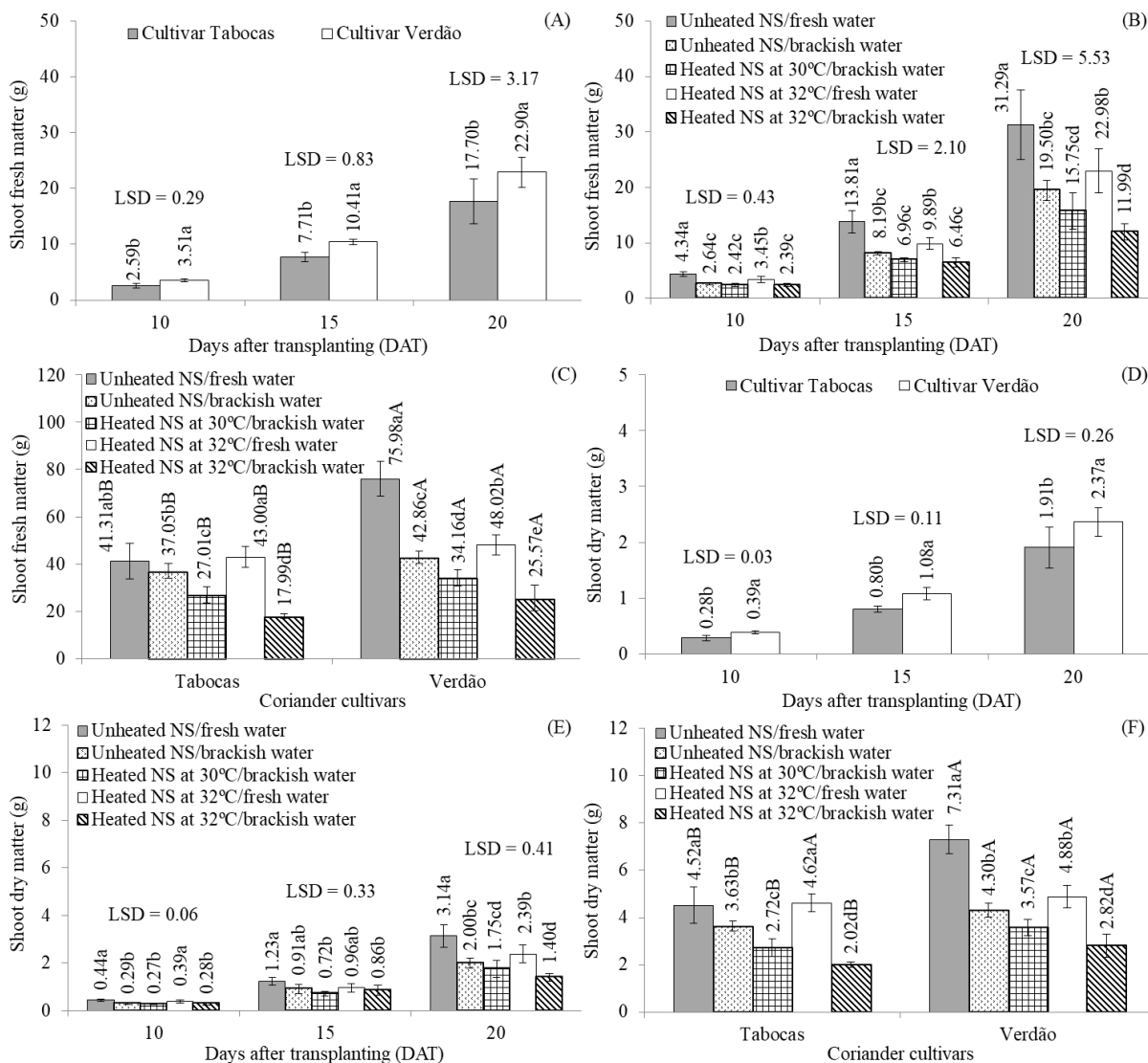
Plants of the cultivar Verdão had larger stem diameter throughout the evaluations, with values approximately 16 to 21% higher than those of the cultivar Tabocas from 10 to 20 DAT (Fig. 3C) and approximately 49% higher at 25 DAT when grown using fresh water and unheated nutrient solution (Fig. 3E). Similar behavior to that of plant height (Fig. 3B) was observed for stem diameter (Fig. 3D) as a function of the combinations of temperatures of the nutrient solutions and water types.

In Experiment II, the height of plants grown with brackish water was lower than the height of plants grown with fresh water, with values of about 17.72, 18.37, 21.37, and 18.64% at 10, 15, 20, and 25 DAT, respectively (Fig. 4A). The height of plants under heated nutrient solution at a temperature of 30°C was only 3.54, 5.62, and 7.22% lower compared to the unheated nutrient solution at 15, 20, and 25 DAT, respectively (Fig. 4A). Reductions in the stem diameter reached 7.44, 13.69, 17.99, and 16.82% at 10, 15, 20, and 25 DAT, respectively, using brackish water

and 5.59 and 14.89% at 15 and 20 DAT, respectively, when using the heated nutrient solution (Fig. 4B).

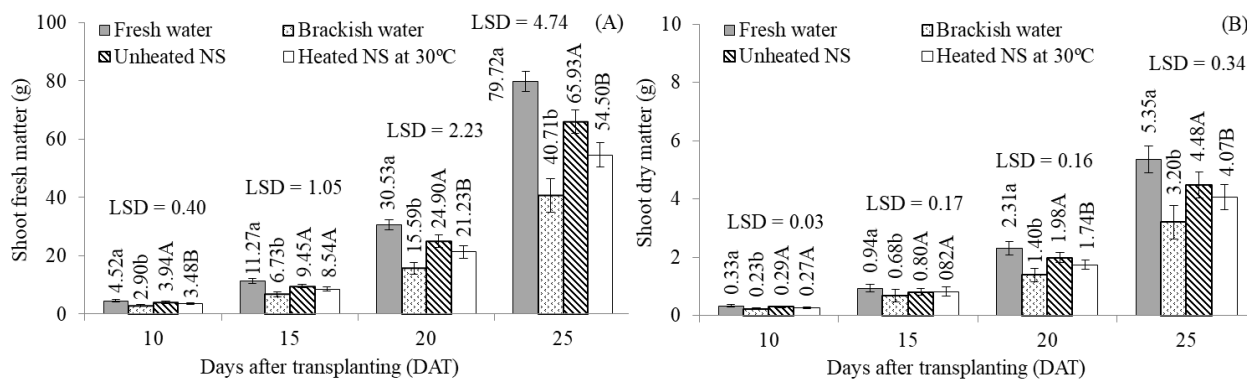
Therefore, according to the results of the present study, the responses of coriander plants to salt and thermal stresses were variable in the different organs and stages of growth. According to Meng et al. (2017), salt stress affects the root system of plants, which is directly exposed to salts, hindering the absorption of water and nutrients and their distribution to other plant organs, thus reducing plant growth. Rebouças et al. (2013) studied coriander of the cultivar Verdão grown on a coconut fiber substrate with different salinity levels in the nutrient solution for 28 days and found that, among the growth variables, the highest reductions occurred in the plant height and leaf area, with values of 12.16 and 13.87% per unit increase in dS m<sup>-1</sup>, whereas the number of leaves decreased by 7.48% per dS m<sup>-1</sup>. Sá et al. (2016) reported the highest reductions in the height than in the stem diameter of coriander plants grown on soil + substrate for 20 days with different salinity levels in the irrigation water. These results denote that plants under salt stress reduced the leaf size rather than stopping producing new leaves (Jiang et al., 2017; Heydarian et al., 2018).

Regarding the production variables for Experiment I, as observed for stem diameter up to 20 DAT, the shoot fresh matter (SFM) (Fig. 5A and 5B) and shoot dry matter (SDM) (Fig. 5D and 5E) of coriander plants were significantly affected by isolated effects of the factors under study (cultivars, temperatures of the nutrient solutions, and water types). A significant interaction between factors for SFM (Fig. 5C) and SDM (Fig. 5F) was observed at 25 DAT. No significant interaction between factors for SFM (Fig. 6A) and SDM (Fig. 6B) was observed during the analyzed period in Experiment II. In addition, isolated effects of water types significantly affected SFM and SDM in all evaluated periods and as a function of temperatures of the nutrient solutions, except at 15 DAT for SFM and 10 and 15 DAT for SDM.



NS – nutrient solution; LSD – least significant difference; vertical bars indicate the standard deviations of the means; in Figures A, B, D and E – means followed by the same letter are not significantly different by the Tukey test at a 0.05 probability level; in Figures C and F – lowercase letters compare the means of the combinations (temperatures of the nutrient solutions using fresh and brackish waters) in each cultivar (with LSD = 4.40 for SFM and LSD = 0.59 for SDM) and uppercase letters compare the means of the cultivars in each combination (with LSD = 3.06 for SFM and LSD = 0.41 for SDM).

FIGURE 5. Mean shoot fresh matter (A, B and C) and shoot dry matter (D, E and F) of coriander plants under under different cultivation conditions using fresh and brackish waters under interaction with temperatures of the nutrient solutions, in a NFT hydroponic system for Experiment I.



NS – nutrient solution; LSD – least significant difference; vertical bars indicate the standard deviations of the means; lowercase letters compare the means of water types (fresh and brackish) and uppercase letters compare the means of the temperatures of the nutrient solution for the isolated effects; means followed by the same letter are not significantly different by the Tukey test at a 0.05 probability level.

FIGURE 6. Mean shoot fresh matter (A) and shoot dry matter (B) of coriander cultivar Verdão under different cultivation conditions using fresh and brackish waters under interaction with temperatures of the nutrient solutions, in a NFT hydroponic system for Experiment II.

The differences regarding SFM (Fig. 5A) and SDM (Fig. 5D) between coriander cultivars in Experiment I was higher than the differences in plant height and stem diameter variables because the cultivar Verdão had more woody and elongated stems. Plants of the cultivar Verdão presented higher SFM and SDM in comparison to the cultivar Tabocas, with values of approximately 36, 35, and 29% and 38, 35, and 24% at 10, 15, and 20 DAT, respectively. The SFM (Fig. 5C) and SDM (Fig. 5F) of the cultivar Verdão at 25 DAT were approximately 84 and 61% higher than the values found for the cultivar Tabocas when grown using fresh water and unheated nutrient solution.

Coriander is marketed based on its fresh matter. Therefore, it is advantageous to keep plants in the hydroponic system until 25 DAT, as the yield can double (cultivar Tabocas) or triple (cultivar Verdão) compared to the harvest at 20 DAT. The SFM of control plants (grown using fresh water and unheated nutrient solution) of the cultivar Verdão in Experiments I (Fig. 5C) and II (Fig. 6A) was similar at 25 DAT, presenting 75.98 and 79.72 g per bunch of 12 plants, respectively.

The SFM yields obtained in the present study were higher than the values found in other studies. Silva et al. (2015) reported SFM values of 49.79 g per bunch of 24 plants at 24 DAT for coriander plants grown in the NFT hydroponic system with a spacing of 0.30 m. Silva et al. (2016a), and Silva et al. (2018a) reported SFM yields of 50.33 and 44.05 g per bunch of 12 plants at 25 DAT for coriander plants grown in the DFT hydroponic system in PVC pipes with a spacing of 0.07 m. The differences in these results are associated with the characteristics of the hydroponic system, growing season, and plant density per cultivation unit and spacing, which determine the availability of the nutrient solution per cultivation unit.

Plants grown in Experiment I using fresh water and unheated nutrient solution (control) presented SFM yields of 4.34, 13.81, and 31.29 g per bunch at 10, 15, and 20 DAT, respectively (Fig. 5B). The highest reductions in SFM yields occurred when plants were grown using brackish water, with values of approximately 43 and 48% at 10 and 15 DAT, respectively, regardless of the temperature of the nutrient solution, compared to the control. Moreover, the decrease was approximately 56% at 20 DAT for plants grown under nutrient solutions heated at temperatures of 30 and 32°C. Decreases in SFM reached approximately 56 and 66% at 25 DAT for cultivars Tabocas and Verdão, respectively, when the plants were grown using brackish water and heated nutrient solution with a temperature of 32°C when compared to the control (Fig. 5C).

Reductions in Experiment II due to thermal stress were lower than those due to salt stress, with values approximately 12 to 17% lower for SFM (Fig. 6A) and 9 to 12% lower for SDM (Fig. 6B) under the heated nutrient solution at a temperature of 30°C from 10 to 25 DAT compared to plants under the unheated nutrient solution. Reductions due to salt stress reached approximately 36 and 40% at 10 and 15 DAT, with the same magnitude (49%) at 20 to 25 DAT.

In the present study, the SFM of plants grown using brackish water was, in general, similar in both experiments (Fig. 5C and 6A). Coriander has been studied under salt stress conditions with different responses to salinity, being considered a moderately tolerant species to salinity based

on the electrical conductivity of the soil saturation extract (ECse) (Aymen & Cherif, 2013; Okkaoğlu et al., 2015). Sá et al. (2016) evaluated coriander plants of the cultivars Verdão and Português Pacífico grown for 20 days on soil and substrate and classified them as moderately sensitive to the salinity of the irrigation water, which presented apparent electrical conductivity of up to 1.94 and 2.70 dS m<sup>-1</sup>, respectively. Yadav et al. (2009) evaluated coriander plants grown in pots on soil with different salinity levels until their maturation stage and classified eight genotypes as tolerant to salinity based on the ECse (up to 6.0 dS m<sup>-1</sup>).

Regarding the SDM yield (Fig. 5E and 5F) in Experiment I, similar behavior to that of SFM (Fig. 5B and 5C) was observed in function of the salt and thermal stresses.

## CONCLUSIONS

The visual quality of coriander plants grown with or without salt stress allowed inferring that their production is possible under temperatures of up to 30°C, despite the observed reduction in shoot fresh matter production.

Coriander plants can also be grown at temperatures of the nutrient solutions of up to 32°C if brackish water is not used.

Coriander plants of the cultivar Verdão are more suitable for the hydroponic system, regardless of the thermal stress of the nutrient solution and the use of brackish water.

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