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Coriander production under nutrient solution prepared with brackish waters and seeding densities[1]

Produção de coentro sob soluções nutritivas preparadas com águas salobras e densidades de semeio

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HIGHLIGHTS:

Increasing seeding density under saline conditions increases the water efficiency of hydroponic coriander.
The height of hydroponic coriander bunches under salinity conditions is not affected by increasing seed density.
Increasing seed density reduces the effect of salinity on hydroponic coriander biomass production.

ABSTRACT: The use of brackish water in semi-arid regions is sometimes necessary, as water is the most limiting factor for agricultural production in these regions. The present study was conducted aiming to evaluate the production of bunches of *Coriandrum sativum* L., cultivar Tabocas, in hydroponic system plants exposed to nutrient solutions prepared with brackish water, obtained by mixing water from a community dam (electrical conductivity of 9.93 dS m^{-1}) with rainwater. The treatments consisted of four values of electrical conductivity of the nutrient solution (1.49, 3.14, 4.87, and 6.44 dS m^{-1}) and three seeding densities (1.0, 1.5, and 2.0 g of seeds per cell), arranged in a completely randomized experimental design in a 4 × 3 factorial scheme, with three replicates. Plant height was not affected up to the electrical conductivity of the nutrient solution of 6.44 dS m^{-1} with increasing seeding density. The electrical conductivity of the nutrient solution up to 6.44 dS m^{-1} at the seeding density of 2.0 g of seed per cell did not affect the shoot fresh and dry mass of the hydroponic coriander, mitigating the deleterious effect of salinity on water use efficiency.

Key words: *Coriandrum sativum* L., semi-arid, soilless culture

RESUMO: O uso de água salobra em regiões semiáridas às vezes é necessário, pois a água é o fator mais limitante para a produção vegetal nessas regiões. O presente estudo foi realizado com o objetivo de avaliar a produção de maços de *Coriandrum sativum* L., cultivar Tabocas, em plantas do sistema hidropônico expostas à soluções nutritivas preparadas com água salobra, obtidas por mistura de água de um açude comunitário (condutividade elétrica de 9.93 dS m^{-1}) com água de chuva. Os tratamentos consistiram em quatro valores de condutividade elétrica da solução nutritiva (1,49, 3,14, 4,87 e 6,44 dS m^{-1}) e três densidades de semeadura (1,0; 1,5 e 2,0 g de sementes por célula), dispostos no delineamento experimental inteiramente casualizado, em esquema fatorial 4 × 3, com três repetições. Até à condutividade elétrica da solução nutritiva de 6,44 dS m^{-1} com o aumento da densidade de semeadura, a altura das plantas não foi afetada. Na densidade de semeadura de 2,0 g de semente por célula, a condutividade elétrica da solução nutritiva, até 6,44 dS m^{-1}, não afetou a massa fresca e seca da parte aérea do coentro hidropônico, mitigando o efeito deletério da salinidade na eficiência do uso da água.

Palavras-chave: *Coriandrum sativum* L., semiárido, cultivo sem solo

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Introduction

Coriander (*Coriandrum sativum* L.) is a horticultural crop belonging to the family Apiaceae, rich in vitamins A, C, B1, and B2, as well as in calcium and iron, and widely used in the pharmaceutical and cosmetic industries (De & De, 2021). However, it is mainly consumed as green leaves in the Brazilian semi-arid (Serri et al., 2021).

The production of vegetables such as coriander in this region of Brazil is sometimes limited by salinity problems that result in the reduction in the osmotic potential and the toxic action of some ions, such as chloride and sodium, causing a reduction in the germination process and plant stand (Bione et al., 2021).

Hydroponic cultivation (Vetrano et al., 2020; Majid et al., 2021), seeding density arrangement (Guerrini et al., 2020), and water mixture (Egbuikwem et al., 2020) stand out among the techniques that aim for the best use of brackish water for crop cultivation.

Regarding seeding density under saline conditions, the increase in plant stand is expected to compensate for part of the biomass loss per unit area. In this sense, Balliu et al. (2021) studied the production and mineral composition of coriander in a low-cost hydroponic system and observed an increase of 5.34 g of total fresh phytomass for each 0.5 g of seeds added per cell.

Mixing waters with different electrical conductivity and increasing water supply may allow the use of brackish waters in the cultivation of salt-sensitive plant species, such as vegetables (Yasuor et al., 2020; Balliu et al., 2021).

In this context, this study was conducted aiming to evaluate the production of bunches of coriander of the cultivar Tabocas in a hydroponic system, using nutrient solutions prepared with brackish water.

Material and Methods

The experiment was carried out in a protected environment at the Experimental Station of the National Institute of Semi-arid – INSA, a Research Unit of the Ministry of Science, Technology, and Innovation – MCTI, in the municipality of Campina Grande, PB, Brazil (7° 16' 41" S and 35° 57' 59" W, at an altitude of 560 m). The means of maximum and minimum temperatures during the experimental period inside the protected environment were 34.56 and 17.85 °C, respectively (Figure 1).

A completely randomized design was used in a 4 × 3 factorial scheme, with three replicates. The treatments consisted of four electrical conductivities of nutrient solutions (EC_{ns}) prepared with brackish water (1.49, 3.14, 4.87, and 6.44 dS m^{-1}) and three seeding densities (1.0, 1.5, and 2.0 g of seeds per cell).

The brackish water came from a community reservoir of the Settlement Vitória (7° 21' S and 36° 0' W, at an altitude of 551 m), located in the municipality of Campina Grande, PB, Brazil. It was characterized using the methodologies recommended by EMBRAPA (2017), with the following attributes: pH = 7.0; EC = 9.93 dS m^{-1}; K^+ = 83.05 mg L^{-1}; Na^+ = 5.672 mg L^{-1}; Ca^{2+} = 220.04 mg L^{-1}; Mg^{2+} = 86 mg L^{-1}; CO_3^{2-} = 0.15 $cmol_c$ L^{-1}; and HCO_3^- = 0.40 $cmol_c$ L^{-1}. Rainwater was collected in the experimental area (EC = 0.015 dS m^{-1}).

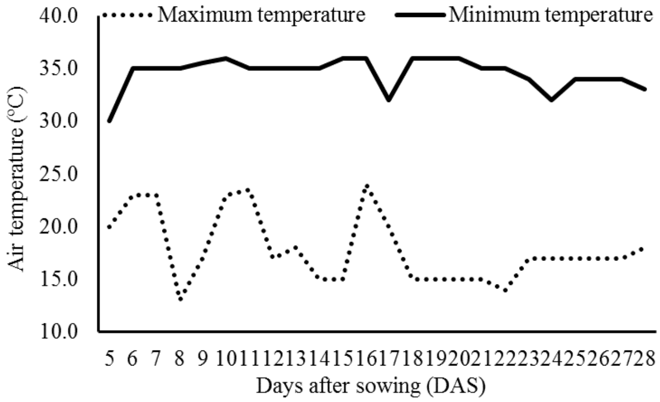


Figure 1. Evolution of the maximum and minimum air temperature inside the protected environment during the experimental period

After collecting and storing the brackish water and rainwater, the mixtures were prepared at the following proportions of brackish water: 0% – only rainwater and 16.67, 33.33, and 50% of brackish water added to the rainwater, which implied electrical conductivity values of 0.0015, 1.66, 3.31, and 4.97 dS m^{-1}, respectively.

Calcium nitrate (750 g), potassium nitrate (500 g), monoammonium phosphate (MAP) (150 g), magnesium sulfate (400 g), copper (0.150 g), zinc sulfate (0.300 g), manganese sulfate (1.500 g), boric acid (1.800 g), sodium molybdate (0.150 g), and Fe-EDTA-13% iron (16 g) were solubilized in each 1000 L of the respective water to prepare the nutrient solution according to the fertilizer amounts, as proposed by Furlani et al. (1999) for leafy vegetables, obtaining electrical conductivity values of 1.49, 3.14, 4.87, and 6.44 dS m^{-1} for the nutrient solution (EC_{ns}).

The nutrient solution was prepared only once at the beginning of the experiment, with no total or partial replacement of nutrients. It was managed in a closed circuit of the circulation system. Forty liters of the respective nutrient solution were applied to the hydroponic channels per circulation event, and the surplus was returned through hoses to the specific recipient for each treatment.

The nutrient solution was manually applied to the hydroponic channels twice a day, at 8 a.m. and 4 p.m. The nutrient solution volume was replaced in the container due to the evapotranspiration of plants every seven days, using the respective water mixture employed in the preparation of each treatment.

The electrical conductivity (EC_{ns}) and pH of the nutrient solution (pH_{ns}) were monitored every two days, from 7 to 35 days after seeding (DAS). No attack of pests or diseases was observed.

The hydroponic system consisted of 100-mm PVC tubes with circular holes (cells) of 60 mm in diameter, spaced at 7 cm. Elbows were installed at the end of the tube and a tap was installed in one of them to provide a 4-cm water depth of nutrient solution inside the leveled tube. The tubes were laid on a vertical wooden structure measuring 6.0 × 1.40 × 1.80 m in length, width, and height, respectively (Santos Júnior et al., 2015).

Seeding was performed in disposable 200-mL plastic cups with perforations at the bottom and sides filled with coconut fiber. The number of seeds sown in each cup varied according to the treatments. After seeding, each cup was inserted into the hydroponic system and irrigated with 10 mL rainwater in the morning and 10 mL in the afternoon until 7 DAS, when circulation of the nutrient solution started. The production in each cup was considered a bunch.

Water consumption (WC) of coriander plants was determined from the sum of weekly replenishments of the nutrient solution metabolized by plants. Water use efficiency of the shoot fresh and dry biomass (WUE-SFB and WUE-SDB) production was calculated at 28 DAS through the relationship between bunch production and consumed water volume. The water content in the shoots (WCS) and roots (WCR) was also determined, according to Benincasa (2003). The shoot biomass production index (SBPI) was calculated by dividing the shoot dry mass by the total dry mass and the ratio between root and shoot biomass (R/S), according to Magalhães (1979).

Shoot fresh (SFM) and dry mass (SDM) and bunch height (BH) of coriander plants were determined at 28 and 35 DAS. The bunch height was determined immediately before harvesting using a measuring tape. Fresh mass was determined on a precision scale with a resolution of 0.01 g immediately after harvesting. Dry mass was obtained by drying the fresh material in a forced-air circulation oven at 60 °C until constant weight. Root fresh mass was obtained after taking the roots from the substrate and placing them on sieves and applying a water jet.

The data were subjected to normality and homoscedasticity tests (Shapiro-Wilk) and analysis of variance at $p \leq 0.05$ using the statistical software SISVAR (Ferreira, 2019). The results in cases in which the electrical conductivity of the nutrient solution (EC_{ns}) resulted in a significant effect were analyzed through regression analysis, while the means of seeding densities were compared by Tukey's test.

Results and Discussion

An increase in the electrical conductivity of the nutrient solution (EC_{ns}) was observed throughout the crop cycle and at the end of the period at all seeding densities, except for EC_{ns} of 1.49 dS m^{-1} (Figure 2). In this case, in addition to the

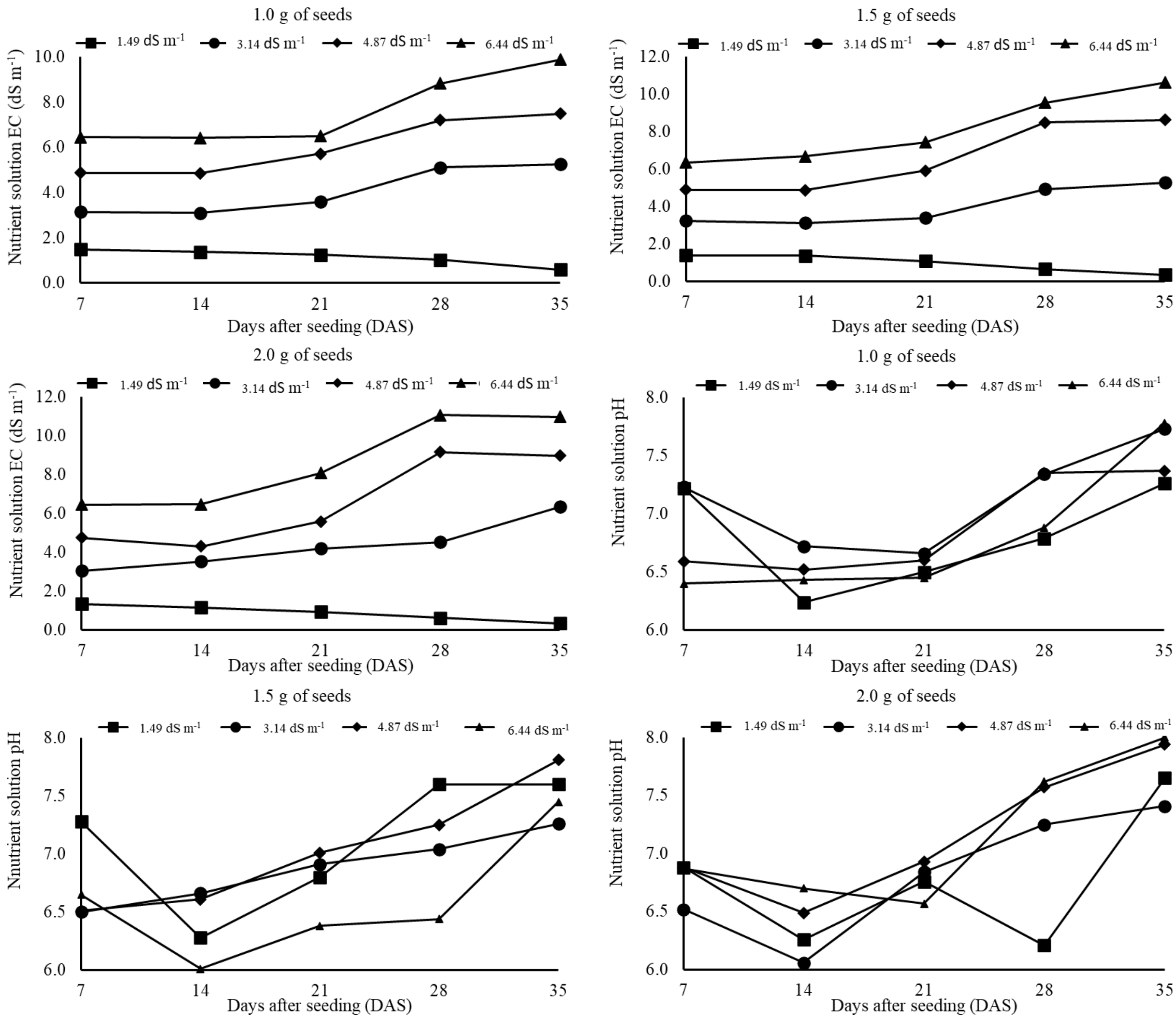


Figure 2. Electrical conductivity (EC) (A, B, and C) and pH (D, E, and F) of the nutrient solutions during the coriander cycle under three seeding densities

absorption of nutrients by the plants, the replenishment of the evapotranspiration water depth with rainwater further diluted the nutrient solution concentration. In contrast, the other treatments showed an influence on the continuous supply of salts due to the completion of the solution volume with the respective brackish water. The increase in EC_{ns} may be attributed to the higher supply of salts due to the higher volume of water necessary to restore the solution volume in the container because of the higher water consumption verified by the increase in plant density (Figures 2A, B, and C).

The pH_{ns} values at all seeding densities up to 28 DAS were within the range recommended by Furlani et al. (1999), that is, between 4.5 and 7.5. A trend towards alkalinity was found at 35 DAS, specifically under nutrient solutions with initial EC_{ns} values of 4.87 and 6.44 dS m^{-1}, which can be attributed to the chemical composition and high salinity of the brackish water (Figures 2D, E, and F).

The mean water consumption of coriander cv. Tabocas was reduced with the increase in EC_{ns} at 28 DAS. The mean water consumption was 1.78, 1.80, and 1.99 L per bunch for the treatments with 1.0, 1.5, and 2.0 g of seeds per cell, respectively, when EC_{ns} was 1.49 dS m^{-1}, for instance. Considering the same variation of seed density, the mean water consumption under EC_{ns} = 6.44 dS m^{-1} was 0.83, 0.92, and 1.20 L per bunch, respectively (Figure 3), corresponding to a reduction of 53.4, 50.6, and 39.7%, respectively.

Similarly, a reduction in water consumption was observed in coriander plants at 35 DAS with an increase in EC_{ns}. Thus,

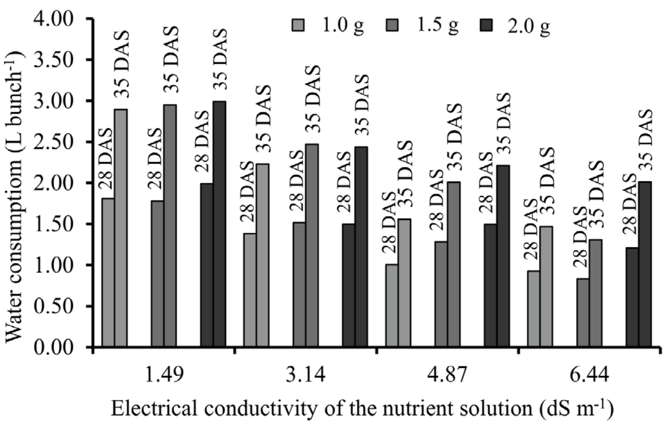


Figure 3. Mean water consumption of coriander plants of the cultivar Tabocas grown in a hydroponic system using nutrient solutions prepared with brackish water under different seeding densities at 28 and 35 days after seeding (DAS)

means of 2.95, 2.89, and 2.99 L per bunch were observed under an EC_{ns} of 1.49 dS m^{-1} when 1.0, 1.5, and 2.0 g of seeds per cell were used, respectively. In contrast, water consumption reached 1.31, 1.47, and 2.01 L per bunch, respectively, under an EC_{ns} of 6.44 dS m^{-1}, corresponding to a decrease of 55.6, 49.1, and 32.8% (Figure 3).

A reduction in water consumption was observed with an increase in EC_{ns}, as verified by Orosco-Alcalá et al. (2021). Concurrently, an increase in water consumption was also observed with the increase in seeding density even at the highest EC_{ns} values (Figure 3).

The interaction between EC_{ns} and seeding density influenced the water use efficiency and the shoot biomass production index. Water content was affected by both factors, whereas the root/shoot biomass ratio was not affected by the interaction or by both factors (Table 1).

The seeding density of 2.0 g of seeds presented a higher water use efficiency for shoot fresh (33 g L^{-1}) and dry biomass (2.39 g L^{-1}) production under an EC_{ns} = 6.44 dS m^{-1} (Figures 4A and B). The highest efficiency values for shoot fresh and dry biomass production were 23.43 and 1.58 g L^{-1}, respectively, for plants under a seeding density of 1.0 g and EC_{ns} = 3.7 dS m^{-1}.

Although water consumption increased with seeding density, doubling seeding density did not imply two times increase in water consumption by the plants in all tested concentrations. The increase in plant density as a strategy to mitigate mass loss per unit area under salt-stress conditions, especially under the bias of water use efficiency, has also been observed for coriander (Ahmadi & Souri, 2018; Vojodi Mehrabanio et al., 2018; Silva et al., 2022).

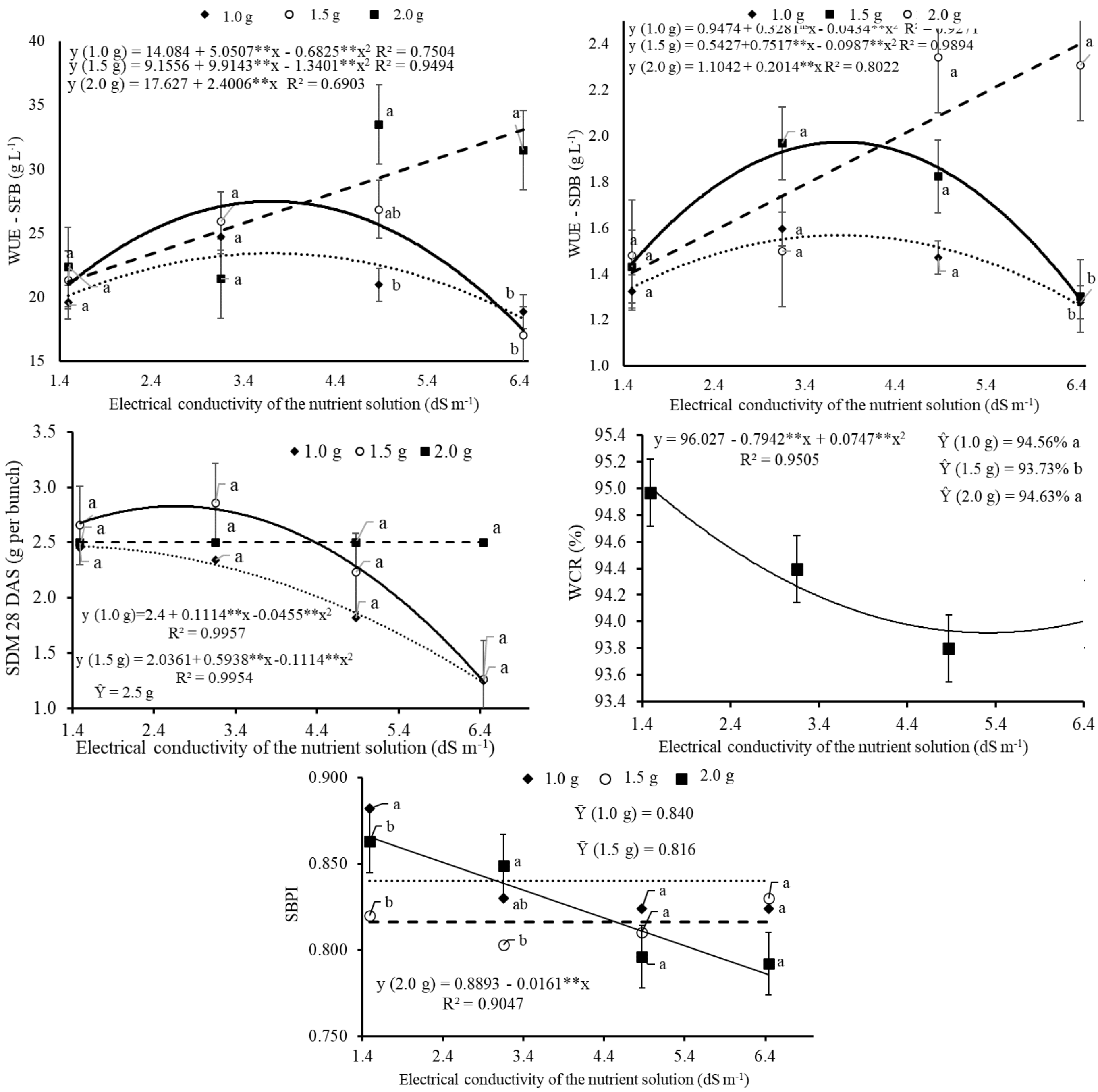
Water content in the shoot and root was influenced ($p \leq 0.01$) by isolated factors, and an estimated reduction of 0.1058 and 0.2129% was observed per unit increase in electrical conductivity of the nutrient solution, respectively (Figures 4C and D). The amount of 1.0 and 2.0 g of seeds led to differences ($p \leq 0.01$) in WCS but no effect ($p > 0.05$) in WCR (Figures 4C and D). The water content was above 92% in the shoot and 93% in the roots in all treatments. In general, water content values above 90% are recommended for leafy vegetables (Scheelbeek et al., 2020), as already observed for coriander (Eskandari et al., 2019; Silva et al., 2020b), lettuce (Visconti et al., 2020), and arugula (Yang et al., 2021).

The maintenance of turgor in plants exposed to salt stress can be associated with osmotic adjustment due to the storage of ions in the vacuole and/or low molecular weight organic

Table 1. Water use efficiency for the production of shoot fresh (WUE-SFB) and dry biomass (WUE-SDB), water content in the shoot (WCS) and root (WCR), shoot biomass production index (SBPI), and root/shoot biomass ratio (R/S) at 28 days after seeding of coriander plants of the cultivar Tabocas under brackish nutrient solutions and different seeding densities

Source of variation	DF	Mean squares					
		WUE-SFB	WUE-SDB	WCS	WCR	SBPI	R/S
[1]EC_{ns}	(3)	0.5888^{ns}	0.0358^{ns}	0.512^{**}	2.287^{**}	0.0013^{ns}	0.0020^{ns}
Linear regression	1	0.1519^{ns}	0.0306^{ns}	1.226^{**}	257.506^{**}	0.00012^{ns}	0.0015^{ns}
Quadratic regression	1	1.3808^{**}	0.0717^{**}	0.009^{ns}	75.460^{**}	0.00158^{ns}	0.0034^{**}
Seeding density (D)	2	1.1482^{**}	0.0765^{**}	0.503^{**}	2.988^{**}	0.0018^{ns}	0.0016^{ns}
EC_{ns} x D	6	0.6771^{**}	0.0380^{**}	0.348^{ns}	1.242^{ns}	0.0027^{**}	0.0011^{ns}
Residual	24	0.2255	0.0131	0.133	0.586	0.00074	0.0005
CV (%)		9.74	7.85	0.39	0.81	3.30	2.92

EC_{ns} – Electrical conductivity of the nutrient solution; CV – Coefficient of variation; DF – Degrees of freedom; ns – Not significant; * and ** – Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F-test



Vertical bars represent the standard error of the mean (n = 3); [ns] – Not significant by the F-test; ** and * – Significant at p ≤ 0.01 and p ≤ 0.05, respectively, by the F-test; Means followed by the same letters indicate no significant difference between treatments by Tukey's test (p ≤ 0.05) for seeding densities at the same electrical conductivity of the nutrient solution

Figure 4. Water use efficiency in the shoot fresh (A) and dry biomass (B) production, water content in the shoot (C) and roots (D), and shoot biomass production index (E) of coriander plants of the cultivar Tabocas under nutrient solutions prepared with brackish water and seeding densities at 28 days after seeding (DAS)

solutes in the cytoplasm (Maaloul et al., 2021) and the control of the uptake of ions through the roots and their transport to the leaves (Guo et al., 2020).

The monitoring of EC_{ns} means within each planting density showed a significant effect ($p \leq 0.05$) for the proportion of shoot dry biomass relative to plant dry biomass only at the seeding density of 2.0 g, with a decrease of 1.81% per unit increment of EC_{ns}. Mean values of 0.840 and 0.816 were found for seeding densities of 1.0 and 1.5 g per cell, respectively (Figure 4E). Seeding densities of 1.0 and 2.0 g of seeds provided better results under EC_{ns} of 1.49 and 3.14 dS m^{-1}. However, increasing density for higher EC_{ns} did not affect the shoot biomass production index (Figure 4E).

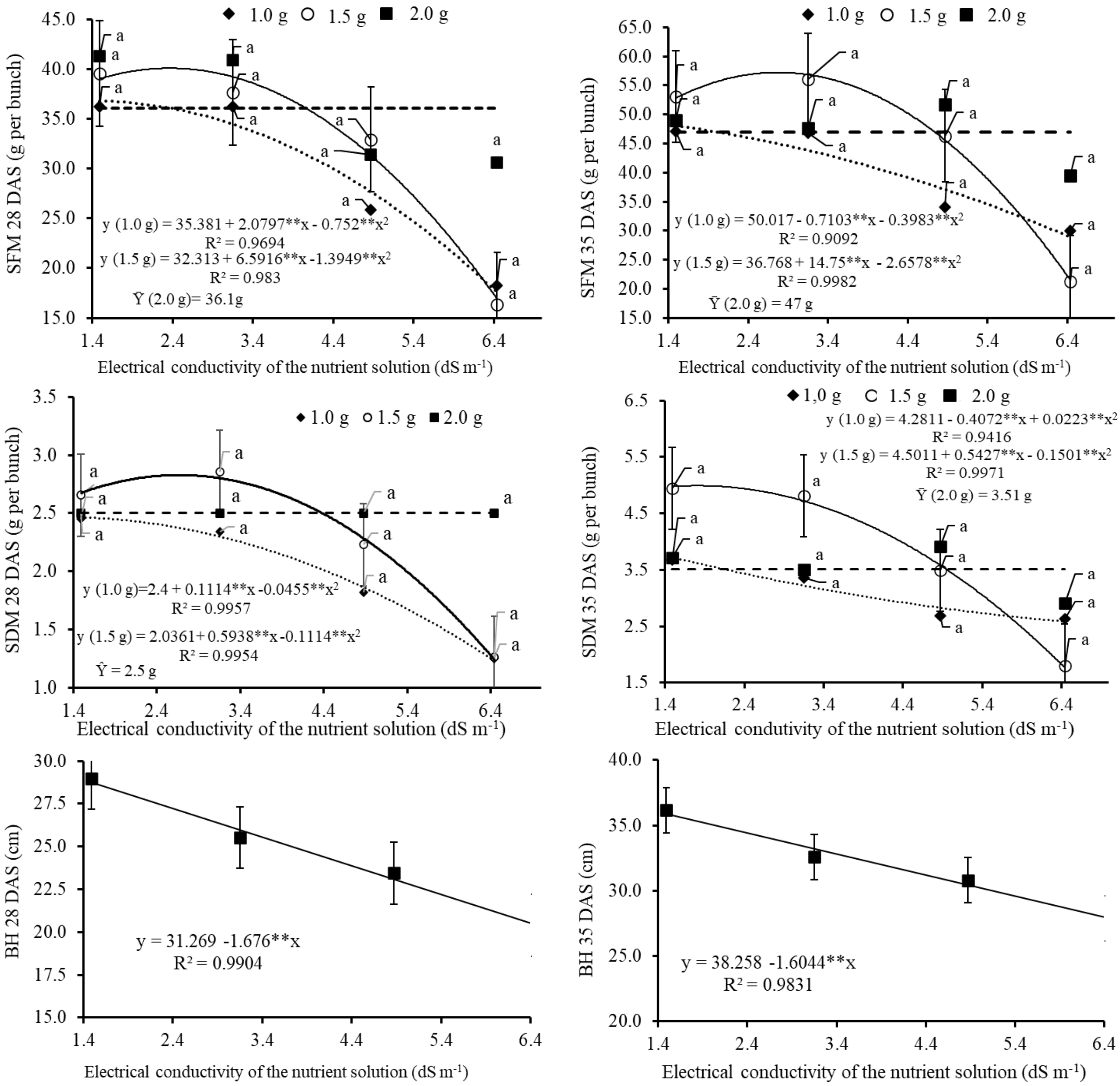
The interaction between EC_{ns} and seeding density influenced ($p \leq 0.01$) shoot fresh (SFM) and dry mass (SDM) and EC_{ns} affected the bunch height (BH) at 28 and 35 DAS (Table 2).

The monitoring analysis of the interaction showed that SFM was not influenced ($p > 0.05$) by the increase in EC_{ns} at 28 and 35 DAS when the density of 2.0 g of seeds was used (Figures 5A and B). The use of 1.5 g of seeds provided a maximum SFM of 40.0991 g per bunch at 28 DAS, with an estimated EC_{ns} of 2.39 dS m^{-1}, while a maximum SFM of 57.23 g per bunch was reached at 35 DAS, with an estimated EC_{ns} of 2.77 dS m^{-1}. SFM was maximum (36.8188 and 46.0693 g per bunch) when using 1.0 g of seeds

Table 2. Shoot fresh (SFM) and dry mass (SDM) and bunch height (BH) of coriander cv. Tabocas under nutrient solutions prepared with brackish waters and seeding densities at 28 and 35 days after seeding (DAS)

Source of variation	DF	Mean squares					
		SFM 28 DAS	SFM 35 DAS	SDM 28 DAS	SDM 35 DAS	BH 28 DAS	BH 35 DAS
EC_{ns}	(3)	497.8^{**}	775.9^{**}	1.897^{**}	4.947^{**}	116.8^{**}	107.8^{**}
Linear regression	1	1301.5^{**}	1872.7^{**}	4.835^{**}	13.74^{**}	347.7^{**}	318.6^{**}
Quadratic regression	1	129.9^{**}	454.6^{**}	0.727^{**}	1.089^{**}	0.357^{ns}	0.99^{ns}
Seeding density (D)	2	147.6^{**}	172.6^{**}	0.871^{**}	1.394^{**}	1.448^{ns}	18.02^{ns}
EC_{ns} x D	6	84.70^{**}	144.4^{**}	2.606^{**}	1.417^{**}	7.674^{ns}	8.22^{ns}
Residual	24	20.2	21.9	2.336	0.197	2.81	6.14
CV (%)		13.9	10.7	13.9	12.8	6.8	7.7

EC_{ns} – Electrical conductivity of the nutrient solution; CV – Coefficient of variation; DF – Degrees of freedom; ns – Not significant; * and ** – Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F-test



Vertical bars represent the standard error of the mean (n = 3). ^{ns} – Not significant by the F-test; * and ** – Significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, by the F-test; Means followed by the same letters indicate no significant difference between treatments by Tukey's test ($p \leq 0.05$) for seeding densities at the same electrical conductivity of the nutrient solution

Figure 5. Shoot fresh (SFM, A and B) and dry mass (SDM, C and D) and bunch height (BH, E and F) of coriander cv. Tabocas under nutrient solutions prepared with brackish waters and different seeding densities at 28 and 35 days after seeding (DAS)

for estimated EC_{ns} values of 1.38 and 0.89 dS m^{-1} at 28 and 35 DAS, respectively. On the other hand, the analysis of seeding densities at all EC_{ns} levels showed no significant difference ($p > 0.05$) for SFM at 28 and 35 DAS (Figures 5A and B).

However, EC_{ns} showed an increase from 2.98 to 4.74 dS m^{-1} at 28 and 35 DAS, respectively (Figures 5A and B).

The reduction in SFM under salt stress has also been recorded for many leafy vegetable crops such as coriander (Silva et al., 2020b) and lettuce (Visconti et al., 2020). However, Abdelaal et al. (2020) conducted a study with peppers and observed that the increase in plant density under salt stress conditions is a compensation strategy for loss of mass per area due to the salinity effect.

The use of 2.0 g of seeds per cell had no effect ($p > 0.05$) on SDM (Figures 5C and D) within the studied EC_{ns} range at 28 and 35 DAS, with means of 2.50 and 3.51 g per bunch, respectively. However, maximum values of 2.8738 and 4.9916 g per bunch were verified with 1.5 g of seeds per cell at 28 and 35 DAS, respectively, for estimated EC_{ns} values of 2.66 and 1.80 dS m^{-1}. Still within the proposed EC_{ns} range, SDM was maximum (2.4681 g per bunch) and minimum (2.4222 g per bunch) at 28 and 35 DAS, respectively, for estimated EC_{ns} values of 1.22 and 9.13 dS m^{-1} (Figures 5C and D). On the other hand, no significant difference ($p > 0.05$) was observed for SDM at 28 and 35 DAS when analyzing the densities within each EC_{ns} (Figures 5C and D).

The increase in plant density in studies carried out with coriander cv. Verdão (Silva et al., 2020a) and Tabocas (Silva et al., 2020b) under saline stress influenced the shoot dry mass when using 15.0 cm spacing between cells, with no significant difference ($p > 0.05$) when different seed masses per cell (109 to 220 seeds) were used for seeding.

A reduction of 1.676 and 1.6044 cm was verified in the bunch height with a unit increase in EC_{ns} at 28 and 35 DAS, respectively (Figures 5E and F). Silva et al. (2020a) also found a higher reduction (2.198 cm) at 28 DAS with a unit increase in EC_{ns} when exposing coriander plants of the cultivar Verdão to salinity. The increase in EC_{ns} may imply a reduction in cell expansion as a result of changes in cell turgor due to a reduction of protein synthesis imposed by salt stress (Zhao et al., 2020), resulting in a decrease in plant growth (Mokrani et al., 2020).

Conclusions

1. A seeding density of 2.0 g of seeds at the highest value of electrical conductivity of the nutrient solution (6.44 dS m^{-1}) mitigated the deleterious effect of salinity on water use efficiency for shoot fresh and dry biomass production of coriander plants in a hydroponic cultivation system.

2. Shoot fresh and dry mass production under a density of 2.0 g of seeds per cell was not sensitive to an increase in EC_{ns}, contrary to what occurs at lower densities.

3. Increasing seeding density did not lead to a reduction in bunch height up to the electrical conductivity of the nutrient solution of 6.44 dS m^{-1} although it reduced the root-shoot ratio.

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