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Production of watermelon seedlings in different substrates under salt stress[1]

Produção de mudas de melancia em diferentes substratos sob estresse salino

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HIGHLIGHTS:

The substrate containing biochar favors the emergence of watermelon seeds.
Irrigation with water of electrical conductivity above 1.5 dS m^{-1} negatively affects watermelon seedling production.
Alternative substrate formulated with biochar favors seedling production by mitigating salt stress.

ABSTRACT: Salt stress affects the production of watermelon (*Citrullus lanatus*) seedlings. However, substrates with alternative materials in their composition can mitigate the harmful effects on the formation of watermelon seedlings. Thus, the objective of the present study was to evaluate the emergence and production of watermelon seedlings grown in different substrates under salt stress. The research was conducted in an agricultural greenhouse belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Redenção, Ceará, Brazil. The experimental design used was completely randomized in a split-plot scheme. The plots were five levels of electrical conductivity of irrigation water (ECw: 0.5, 1.5, 2.5, 3.5, and 4.5 dS m^{-1}) and the subplots consisted of two formulations of substrates (SB1: sandy soil + sand + bovine manure; and SB2: sandy soil + sand + biochar; both in a 1:1:1 proportion on volume basis), with five repetitions of 25 seeds. The increase in the electrical conductivity of irrigation water from 1.5 dS m^{-1} reduces the percentage, speed index, and mean speed of emergence and increases the mean time of emergence of the watermelon crop. Substrate formulated with biochar reduces the time and increases the emergence indexes, besides enabling higher growth and biomass accumulation of watermelon seedlings. Salt stress reduces the growth, biomass, and quality of watermelon seedlings, but with less intensity with the addition of biochar.

Key words: *Citrullus lanatus*, emergence, biochar, salinity

RESUMO: O estresse salino afeta a produção de mudas de melancia (*Citrullus lanatus*). Porém, substratos com materiais alternativos na sua composição podem mitigar os efeitos deletérios na formação de mudas de melancia. Dessa forma, objetivou-se avaliar no presente estudo a emergência e a produção de mudas de melancia cultivada em diferentes substratos sob estresse salino. A pesquisa foi desenvolvida em estufa agrícola pertencente à Universidade da Integração Internacional da Lusofonia Afro-Brasileira, Redenção, Ceará, Brasil. O delineamento experimental adotado foi inteiramente casualizado em esquema de parcelas subdivididas. As parcelas corresponderam à cinco níveis de condutividade elétrica da água de irrigação (CEa: 0,5, 1,5, 2,5, 3,5 e 4,5 dS m^{-1}) e as subparcelas à duas formulações de substratos (SB1: areia + arisco + esterco bovino; e SB2: areia + arisco + biochar; ambos com proporção 1:1:1 base de volume), com cinco repetições de 25 sementes. A elevação da condutividade elétrica da água a partir de 1,5 dS m^{-1} reduz os índices de emergência, e aumenta o tempo médio de emergência da cultura da melancia. Substrato formulado com biochar favorece os índices de emergência, além de possibilitar maior taxa de crescimento e desenvolvimento da biomassa de plântulas de melancia. O estresse salino reduz o desenvolvimento e a qualidade de plântulas de melancia, porém com menor intensidade com adição de biocarvão.

Palavras-chave: *Citrullus lanatus*, emergência, biochar, salinidade

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Introduction

Watermelon (*Citrullus lanatus*) is an annual crop, native to Africa, belonging to the Curcurbitaceae family. It is a species of significant importance in Brazil due to its short cycle, with a good financial return, and relatively low initial investment (Silva Junior et al., 2020).

The Brazilian Northeast region stands out as the main producer in Brazil; however, the presence and use of inferior-quality water (brackish) has been affecting the establishment of seedlings, due to changes in osmotic potential, ionic toxicity, and imbalance in nutrient uptake, caused by the accumulation of toxic ions, leading to low-quality seedlings (Santos et al., 2018; Ó et al., 2020). Ó et al. (2020), when evaluating the watermelon seedlings under salt stress, reported reduced development under irrigation with saline water of 3.5 dS m^{-1}.

Seedling production is one of the most important stages in the production of fruit species (Lessa et al., 2022). Thus, it is important to investigate the effects of salt stress, including on emergence, due to the reduction of the water potential gradient between the seed and substrate, besides immobilizing reserves and causing disturbances in the embryonic axis (Freire et al., 2018; Dehnavi et al., 2020).

It is worth noting that the substrate plays an important role in the obtaining of quality seedlings, as it must provide a favorable environment, favoring the adequate supply of water and air, and have an excellent texture, structure, pH, and fertility (Barros et al., 2017; Santos et al., 2022). Among the available alternative materials, it is found that biochar, with its benefits related to its properties (high porosity, high retention, and availability of water and high cation exchange capacity), favors the retention of nutrients, thereby avoiding their losses and the direct nutrient supply (Laurentino et al., 2021). Silva Júnior et al. (2020), when using carbonized rice husk and biochar in watermelon seedlings, found an attenuating effect for salt stress.

Given the above, the objective of the present study was to evaluate the emergence and production of watermelon seedlings grown in different substrates under salt stress.

Material and Methods

The study was conducted in September 2020, in an agricultural greenhouse, at the Unidade de Produção de Mudas Auroras (UPMA) of the Universidade da Integração Internacional da Lusofonia Afro-Brasileira (UNILAB), Auroras Campus, in the municipality of Redenção, Ceará, Brazil (04° 13' 05" S, and 38° 2' 46" W, with an average altitude of 96 m). The climate of the region is of the BSh' type with very high temperatures and predominant rainfall in the summer and fall seasons (Alvares et al., 2013). The data of air temperature and relative air humidity were monitored by a Data logger (HOBO® U12-012 Temp/RH/Light/Ext) (Figure 1).

The experimental design used was completely randomized in a split-plot scheme with five repetitions. The plots were composed of five levels of electrical conductivity of irrigation water (ECw: 0.5, 1.5, 2.5, 3.5, and 4.5 dS m^{-1}) and the subplots corresponded to two substrate formulations (SB1: sandy soil + sand + bovine manure; and SB2: sandy soil + sand + biochar; both with 1:1:1 proportion (volume basis)), with 25 seeds per repetition.

The water salinity levels of 0.5 dS m^{-1} (control) and 1.5, 2.5, 3.5, and 4.5 dS m^{-1} tested in this research are commonly observed in the semi-arid region of Northeastern Brazil. Thus, the choice of these aimed to evaluate the germination behavior and the development of seedlings in different substrates under conditions below (1.5 and 2.5 dS m^{-1}) and above (3.5 and 4.5 dS m^{-1}) the salinity threshold, which is 3.0 dS m^{-1} for watermelon (Ayers & Westcot, 1999).

Samples of the substrates were sent to the laboratory of the Universidade Federal do Ceará (UFC) for analyses of chemical attributes (Table 1) according to the methodologies described by Teixeira et al. (2017).

The irrigation waters were prepared from the supply water (0.5 dS m^{-1} - lowest ECw) using the salts NaCl, $CaCl_2.H_2O$, and $MgCl_2.6H_2O$, whose amount was determined to obtain the desired ECw (1.5, 2.5, 3.5, and 4.5 dS m^{-1}), in the equivalent proportion 7:2:1 (Medeiros, 1992), following the relationship between ECw and their concentration ($mmol_c\ L^{-1} \approx EC \times 10$) according to Richards (1954). The electrical conductivity of water was monitored periodically with a benchtop water tester (AZ® 806505 pH/Cond./TDS/Sal). Irrigation was performed daily manually, following the methodology proposed by Marouelli & Braga (2016), until the water drained through the bottom of the trays, using a standardized leaching depth of 8%.

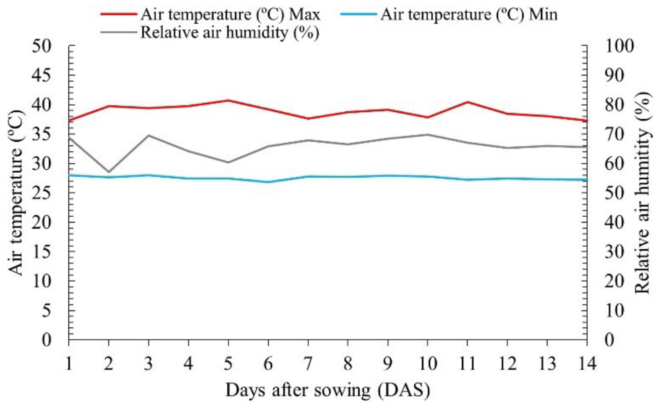


Figure 1. Mean values of maximum (Max) and minimum (Min) temperatures and relative air humidity observed during the experimental period

Table 1. Chemical characteristics of the substrates (SB1: sandy soil + sand + bovine manure; and SB2: sandy soil + sand + biochar) before the beginning of the treatments

Substrates	OM[1]	N	P	Ca^{2+}	K^+	Mg^{2+}	Na^+	$H^+ + Al^{3+}$	Al	SB[2]	CEC[3]	V[4]	ECse[5]	pH
	(g kg^{-1})		(mg kg^{-1})	($cmol_c\ kg^{-1}$)								(%)	(dS m^{-1})	H_2O
SB1	14.74	0.93	20	4.90	0.58	0.90	0.26	0.33	0.00	6.64	6.97	95	1.34	7.0
SB2	8.69	0.51	85	2.50	0.51	1.60	0.18	0.66	0.05	4.79	5.45	88	0.78	7.1

[1]OM – Organic matter; [2]SB – Sum of bases ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$); [3]CEC – Cation exchange capacity - [$Ca^{2+} + Mg^{2+} + Na^+ + K^+ + (H^+ + Al^{3+})$]; [4]V – Base saturation - ($Ca^{2+} + Mg^{2+} + Na^+ + K$+/ CEC) × 100; [5]ECse – Electrical conductivity of the saturation extract of the substrate

Sowing was performed in polystyrene trays with 200 cells of 40 cm³, at a depth of 2 cm, with one seed per cell. The seeds used came from the watermelon hybrid "Crimson Sweet" (Topseed® - AGRISTAR, Santo Antônio de Posse, Brazil), which is characterized as a medium-sized and vigorous plant, rounded fruits with light green color, and dark stripes, intense red pulp, and brown seeds, suitable for marketing.

One day after sowing the number of emerged seedlings started to be counted, using as a criterion the emergence of leaves with expanded cotyledons, until stabilization (14 days after sowing - DAS). During this period the following variables were measured: emergence percentage (EP), correlating the number of emerged seedlings with the number of sown seeds,; emergence speed index (ESI), by daily counting of emerged seedlings, using the methodology of Maguire (1962); mean time of emergence (MTE), by daily counting, according to the methodology proposed by Labouriau (1983), mean speed of emergence (MSE) according to Carvalho & Carvalho (2009).

At 14 DAS, seedling height (SH) was measured from the base to the apex, root length (RL), from the main root to the root apex, both with the help of a ruler graduated in centimeters, and stem diameter (SD), measured close to the substrate with a digital caliper, in millimeters. To obtain the biomass, the seedlings were placed in paper bags, identified, and placed in a forced air circulation oven at 60 °C for 72 hours until reaching constant mass. The data were then used to determine the shoot dry matter (SDM) and root dry matter (RDM) by weighing on analytical scales and the total dry matter (TDM = SDM + RDM) in g per plant.

From the data obtained from the previous evaluations, the quality of the seedlings was determined through the Dickson quality index (DQI) (Dickson et al., 1960), according to Eq. 1:

$$DQI = \frac{TDM(g)}{\frac{SH(cm)}{SD(mm)} + \frac{SDM(g)}{RDM(g)}} \quad (1)$$

where:

DQI - Dickson quality index;
TDM - Total dry matter (g per plant);
SH - Seedling height (cm);
SD - Stem diameter (mm);
SDM - Shoot dry matter (g per plant); and,
RDM - Root dry matter (g per plant).

To assess normality, the data obtained were subjected to the Kolmogorov-Smirnov test ($p \leq 0.05$). After checking normality, the data were subjected to analysis of variance by the F test. In cases of significance, for ECw regression analysis was performed, while in cases of significance of interaction the substrates were analyzed considering each level of ECw, and the substrate data were subjected to the Tukey test ($p \leq 0.05$), using Assistat software 7.7 Beta (Silva & Azevedo, 2016).

Results and Discussion

All variables related to the rate of emergence (percentage, speed index, mean time, and mean speed) and to the initial growth, stem diameter, and root length were influenced by the factors studied, ECw ($p \leq 0.05$) and substrates ($p \leq 0.01$). On the other hand, seedling height had a significant response to the interaction between the factors ($p \leq 0.01$) (Table 2).

The substrate composed of sandy soil + sand + bovine manure (SB1) caused a reduction of 5.13% in the emergence of watermelon seedlings compared to SB2 (sandy soil + sand + biochar) (Table 2). This effect may be related to the smaller amount of macropores provided by the manure and consequently the lower water absorption, resulting in lower seed imbibition. On the other hand, biochar is composed of larger particles with lower degree of compaction, generating greater water absorption and favoring emergence (Lisboa et al., 2018; Goes et al., 2019).

As in the present study, Goes et al. (2019), evaluating okra (*Abelmoschus esculents* L.) emergence, reported that substrate composed of sand + sandy soil + bovine manure (1:1:1 - volume basis) promoted a lower percentage of emergence (44.44%).

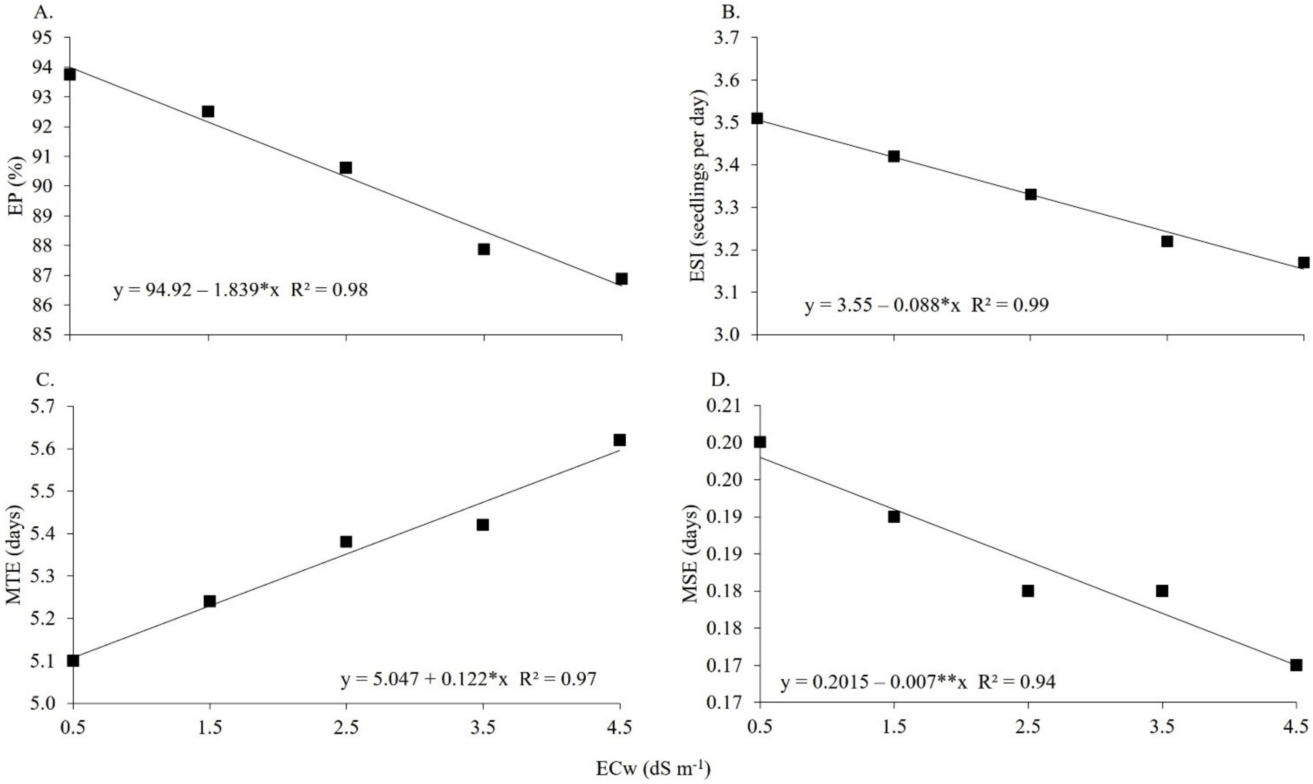
Increasing the electrical conductivity of irrigation water led to a linear reduction in the percentage of emergence. According to the equation, the extreme values were 93.75% at the lowest salinity level (0.5 dS m^{-1}) and 86.87% at the highest ECw (4.5 dS m^{-1}), corresponding to a reduction of 1.93% per unit increase of ECw (Figure 2A).

This negative result of salt stress may be reflected in the germination process of watermelon, which is of the epigeal

Table 2. Summary of the analysis of variance and means for emergence percentage (EP), emergence speed index (ESI), mean time of emergence (MTE), mean speed of emergence (MSE), seedling height (SH), stem diameter (SD), and root length (RL) of watermelon seedlings under different electrical conductivities of irrigation water (ECw) and two substrates (SB)

Source of variation	DF	Mean squares						
		EP	ESI	MTE	MSE	SH	SD	RL
ECw	4	100.39*	0.19*	0.42*	0.00051**	19.43**	0.07**	2.95**
Residual	20	88.67	0.04	0.09	0.00009	0.23	0.02	0.47
Substrates	1	282.03**	2.98**	14.17**	0.017**	1.09^{ns}	0.10**	3.86**
Residual	20	33.98	0.05	0.16	0.00018	0.54	0.01	0.37
ECw × Substrate	4	57.42^{ns}	0.07^{ns}	0.22^{ns}	0.00020^{ns}	2.82**	0.009^{ns}	0.14^{ns}
CV - ECw (%)	-	10.45	6.66	5.58	4.92	6.67	8.85	12.14
CV - Substrates (%)	-	6.47	6.69	7.63	7.06	10.03	5.39	10.79
		%	seedlings per day	days	days	cm	mm	cm
SB1		87.75 b	3.09 b	5.90 a	0.17 b	7.18 a	1.90 b	5.38 b
SB2		92.50 a	3.58 a	4.84 b	0.20 a	7.48 a	2.00 a	5.93 a

DF - Degrees of freedom; CV - Coefficient of variation; *; **, ns - Significant at $p \leq 0.05$ and $p \leq 0.01$, and not significant, respectively, by F test; SB1 - Sandy soil + sand + bovine manure (1:1:1 - volume basis); and SB2 - Sandy soil + sand + biochar (1:1:1- volume basis)



*, ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively

Figure 2. Emergence percentage – EP (A), emergence speed index – ESI (B), mean time of emergence – MTE (C), and mean speed of emergence – MSE (D) of watermelon seedlings under different electrical conductivities of irrigation water (ECw)

type, i.e., the cotyledons and the apical bud are elevated above the ground by the elongation of the hypocotyl, requiring a satisfactory water maintenance. However, the increase in the salinity of the irrigation water reduces the water potential, leading to lower water absorption by the seeds and reducing the efficiency of the germination process of watermelon seeds (Freire et al., 2018; Ó et al., 2020). Linear reduction in the percentage of emergence with increasing ECw was also reported by Santos et al. (2018), working with three zucchini (*Cucurbita moschata*; *Cucurbita maxima*; *Cucurbita moschata*) genotypes, where the reduction was 20.27, 16.66, and 15.27% for each unit increase in irrigation water salinity.

The ESI was significantly reduced by the use of the substrate with bovine manure in the composition compared to biochar, with values of 3.09 and 3.58 seedlings per day, respectively, representing a reduction of 13.68% (Table 2). The biochar present in SB2 has attributes that assist in seedling emergence and seedling production, such as good water retention capacity and higher phosphorus content, favoring good germination performance and consequently better emergence rate (Barros et al., 2017). Higher emergence speed index in substrates containing biochar was also reported by Oliveira et al. (2019) in cowpea crop.

According to the regression analysis in Figure 2B, the emergence speed index was reduced by 9.68% between the extreme salinity levels (0.5 and 4.5 dS m^{-1}), with a reduction of 2.48% per unit increment in electrical conductivity of water. These results may be related to reduced water potential, which reduces the absorption of water by the seeds, or ion toxicity, as such factors together inhibit germination and consequent emergence when plants are irrigated with saline solutions (Benadjaoud et al., 2022; Semedo et al., 2022).

In accordance with the data found in this research, Santos et al. (2018), working with three zucchini genotypes, observed a reduction in the emergence speed index for both as the salinity level of the irrigation water increased. Semedo et al. (2022) found a reduction of 16.27% in *Passiflora edulis* L. for the increment of salinity levels in the irrigation water from 0.3 to 3.0 dS m^{-1}.

According to Table 2, the formulation of the substrate from bovine manure provided a longer mean time of emergence (5.90 days) compared to biochar present in the composition (4.84 days). This effect of bovine manure may be related to the higher ECse of the substrate (1.34 dS m^{-1} - Table 1), i.e., the increased concentration of soluble salts results in a lower osmotic potential of the solution, influencing lower water availability and imbalance in water uptake by seeds (Freire et al., 2018; Silva Junior et al., 2020; Benadjaoud et al., 2022).

Higher mean time of emergence in a substrate composed of sandy soil + sand + bovine manure (1:1:1 - volume basis) was also found by Goes et al. (2019) in okra crop. Silva Junior et al. (2020), on the other hand, observed no significant difference between different substrate formulations (SB1 = vermiculite + coconut fiber, SB2 = manure + soil, SB3 = carbonized rice husk + soil, SB4 = biochar + soil; all in the ratio of 1:1 - volume basis) for the mean time of emergence in the watermelon crop (cv. Crimson Sweet) in a protected environment.

The mean time of emergence according to the regression equation was linearly retarded by 2.41% per unit increment of ECw, as shown in Figure 2C. Thus, when seedlings were irrigated with the highest salinity level (4.5 dS m^{-1}) there was a 10% increase in emergence time compared to plants irrigated with the lowest salinity level (0.5 dS m^{-1}).

The increase in the concentration of salts from the irrigation water reduces the absorption of water by the seeds and may cause a delay in the onset of metabolic processes that initiate germination and seedling emergence due to osmotic stress and pseudo-dryness. Dehnavi et al. (2020) reported that salinity causes a reduction in seed germination.

Ó et al. (2020) also observed an increase in mean time of emergence in mini watermelon seedlings when irrigated with higher salinity water (5.5 dS m^{-1}). In contradiction to the results of this study, Silva Junior et al. (2020) found no significant difference in the mean time of emergence in watermelon (Crimson Sweet) seeds using water of different salinity levels (0.8 and 2.5 dS m^{-1}) in a protected environment.

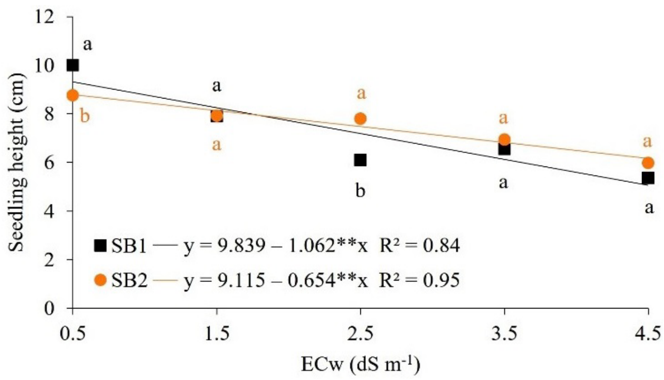
The substrate composed of biochar (SB2) promoted a higher mean speed of emergence, with 15% superiority compared to SB1 (sandy soil + sand + bovine manure) (Table 2). The positive influence of the substrate composed of biochar may be associated with the fact that biochar contains considerable amounts of nutrients, such as N, P, and S, and can absorb soluble organic compounds, in addition to retaining water and serving as a shelter for microorganisms (Vendruscolo et al., 2018).

Trends similar to that found in the present study were reported by Silva Junior et al. (2020) with watermelon crop sown in substrate containing biochar. Similarly, Goes et al. (2019) also recorded a positive effect for mean speed of emergence in seeds of okra plants in a substrate composed of biochar.

The mean speed of emergence of watermelon seedlings was reduced with increasing ECw. According to the equation, the reduction per unit increase in salinity level was 3.47% (Figure 2D). The salts present in the irrigation water caused a reduction in the osmotic potential of the substrate, which possibly affected the availability of water to be absorbed by the seeds and consequently germination. The study conducted by Silva Junior et al. (2020) in watermelon crop revealed a similar trend, that is, salt stress decreased the mean speed of emergence in the substrate composed of biochar + soil in a 1:1 ratio on volume basis.

The increase in ECw caused a linear reduction in the height of watermelon seedlings, regardless of the substrate used (Figure 3). The reductions according to regression analysis were 10.79 and 7.17% per unit increment of ECw for SB1 and SB2, respectively. It is possible to observe that, at the highest ECw (4.5 dS m^{-1}), SB2 was 21.93% better than SB1. When analyzing the interaction between different electrical conductivities of irrigation water and substrates (Figure 3), it is observed that substrates 1 and 2 do not differ significantly from each other at ECw of 1.5, 3.5, and 4.5 dS m^{-1}, but SB1 was statistically superior to SB2 at ECw of 0.5 dS m^{-1}, while SB2 was superior at the ECw of 2.5 dS m^{-1} for seedling height.

These reductions for both substrates can be justified due to changes in the osmotic potential of the substrates, causing less water uptake, and the toxicity of ions (Na^+ and Cl^-) present in irrigation water inhibit cell elongation and division (Freire et al., 2018; Lessa et al., 2022). However, SB2 (sandy soil + sand + biochar) enabled greater heights under higher ECw levels (as



** - Significant at p ≤ 0.01 by F test, respectively; SB1 - Sandy soil + sand + bovine manure (1:1:1 - volume basis); and SB2 - Sandy soil + sand + biochar (1:1:1 - volume basis). Means followed by different letters at same ECw indicate significant difference by F test ($p \leq 0.05$)

Figure 3. Height of watermelon seedlings under different electrical conductivities of irrigation water (ECw) and substrates (SB)

that of 2.5 dS m^{-1}), possibly due to the substrate's water-holding capacity, in addition to greater drainage capacity, causing salts to be leached out more easily (Barros et al., 2017; Silva Junior et al., 2020).

When analyzing the production of yellow passion fruit seedlings under salt stress, Oliveira et al. (2015a) observed a 37% reduction in height with increasing irrigation water electrical conductivity (0.3 to 3.5 dS m^{-1}), regardless of the substrate used (soil + bovine manure (2:1 - volume basis); and soil + commercial substrate (2:1 - volume basis)).

The use of SB2 (sandy soil + sand + biochar) promoted a greater stem diameter (2 mm) compared to SB1 (sandy soil + sand + bovine manure) (1.90 mm), corresponding to a percentage increase of 5% (Table 2). The substrate containing biochar enabled a fast and efficient drainage, providing good oxygenation for the roots, large aeration space in the substrate, and a pH close to neutrality.

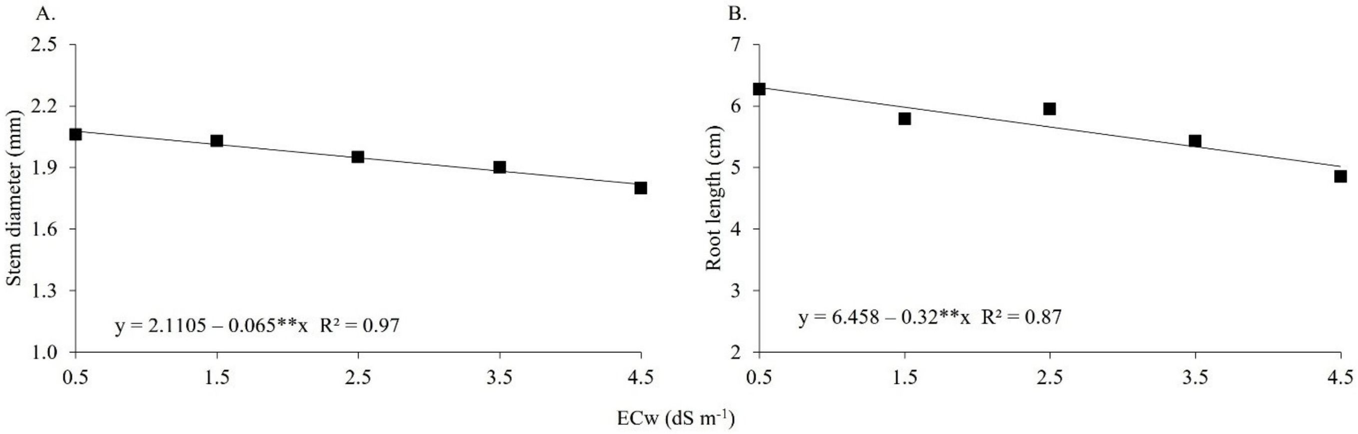
Greater stem diameter with the use of substrate containing biochar was reported by Barros et al. (2017), in passion fruit (*Passiflora edulis* - BRSGA1), with the highest values obtained at the proportions of 25, 50, and 75% biochar, with average of 3.3 mm.

According to Figure 4A, the increase in irrigation water salinity negatively affected stem diameter, causing a 12.3% reduction between the extreme conductivity levels (0.5 and 4.5 dS m^{-1}) according to the regression equation.

The present reduction is related to morphological alterations because of the increased concentration of salts in the irrigation water, causing water and nutritional imbalance; in addition, the exacerbated metabolic expenditure triggers a series of ionic alterations, thus affecting seedling development (Oliveira et al., 2015a; Pinheiro et al., 2018).

Reduction in stem diameter with increasing irrigation water salinity has also been reported by Oliveira et al. (2015a) and Alves et al. (2019) in passion fruit (*Passiflora edulis* f. flavicarpa Deg.) (13.8% under 3.5 dS m^{-1}) and tamarind (*Tamarindus indica* L.) (57.7% under 6.5 dS m^{-1}) crops, respectively.

According to Table 2 for the variable root length, the two substrates evaluated differed statistically from each other; SB1 led to lower length (5.37 cm), while SB2 promoted greater root development (5.93 cm).



** - Significant at $p \leq 0.01$ by F test, respectively

Figure 4. Stem diameter (A) and root length (B) of watermelon seedlings under different electrical conductivities of irrigation water (ECw)

This result reveals the importance of this substrate in terms of nutrient availability and aeration combined with water absorption capacity, which are fundamental characteristics for radicle development. Thus, biochar (within the proper proportions) can favor root development because it increases porosity and water retention in the substrate (Goes et al., 2019; Santos et al., 2022).

In disagreement with the results obtained in the present study, Silva Junior et al. (2020) reported reduced root length in watermelon seedlings using substrate containing biochar (soil + biochar - 1:1 - volume basis). Santos et al. (2022) reported a positive effect of biochar (23.69%) on root growth of *Schinus terebinthifolius*.

The root length of watermelon seedlings (Figure 4B) was linearly reduced with increasing ECw, with a reduction of 0.32 cm (4.95%) per unit increase in salinity level. The reduction of the root system with increasing salinity is related to water restrictions imposed by salt stress due to osmotic imbalances, causing toxicity and disturbances of nutritional nature, and consequently less development of the radicle (Lessa et al., 2022).

When working with yellow passion-fruit seedling production, Lessa et al. (2022) reported an isolated effect for ECw, as these authors observed that increasing salinity from 0.3 to 3 dS m^{-1} reduces root length.

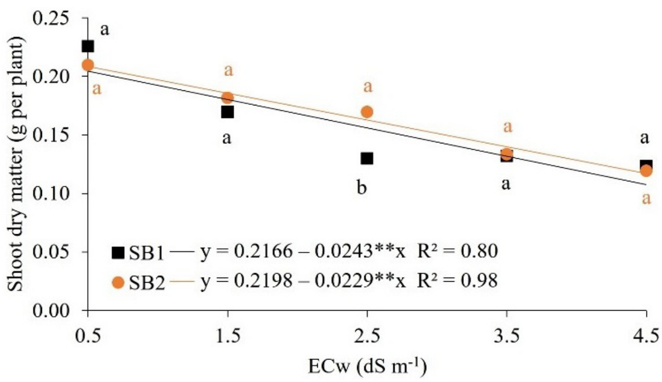
According to the summary of the analysis of variance for watermelon seedling biomass characteristics, shoot dry matter was influenced by the interaction between factors (ECw × Substrates - $p \leq 0.01$) in the same way as the Dickson quality index ($p \leq 0.05$). On the other hand, root dry matter and total dry matter were influenced separately by the factors ECw and substrates ($p \leq 0.01$) (Table 3).

Shoot dry matter was linearly reduced with the increment of ECw in both substrates (Figure 5). When analyzing the regression, it is observed that SB2 (sandy soil + sand + biochar) caused a reduction per unit increment of salinity of 11.21%, while SB1 (sandy soil + sand + bovine manure) resulted in lower averages with a reduced rate per unit increment of 10.41%. For the interaction between the studied factors, there was no significance between the two substrates at ECw levels of 0.5. 1.5, 3.5, and 4.5 dS m^{-1}. In the water of 2.5 dS m^{-1}, SB2 was statistically superior to SB1 for shoot dry matter. This effect caused by salt stress leads to inhibition, translocation, and synthesis of essential hormones for plant growth, consequently reducing biomass production. However, the addition of biochar promoted better chemical conditions, leading to higher levels of shoot dry matter, regardless of the salinity level (Freire et al., 2018; Silva Junior et al., 2020).

Table 3. Summary of the analysis of variance and means for shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), and Dickson quality index (DQI) of watermelon seedlings under different electrical conductivities of irrigation water (ECw) and substrates (SB)

Source of variation	DF	Mean squares			
		SDM	RDM	TDM	DQI
ECw	4	0.015**	0.045**	0.093**	0.003*
Residual	20	0.0004	0.005	0.007	0.0007
Substrates	1	0.001*	0.048**	0.063**	0.004**
Residual	20	0.00018	0.004	0.004	0.0003
ECw × Substrate	4	0.0016**	0.012ns	0.013ns	0.001*
CV - ECw (%)	-	12.95	17.45	23.24	17.50
CV - Substrates (%)	-	8.50	14.07	19.22	12.35
		g per plant			
SB1		0.15 b	0.17 b	0.32 b	0.06 b
SB2		0.16 a	0.23 a	0.40 a	0.09 a

DF - Degrees of freedom; CV - Coefficient of variation; *; **, ns - Significant at $p \leq 0.05$ and $p \leq 0.01$, and not significant, respectively, by F test; SB1 - Sandy soil + sand + bovine manure (1:1:1 - volume basis); and SB2 - Sandy soil + sand + biochar (1:1:1 - volume basis)



** - Significant at $p \leq 0.01$ by F test, respectively; SB1 - Sandy soil + sand + bovine manure (1:1:1 - volume basis); and SB2 - Sandy soil + sand + biochar (1:1:1 - volume basis). Means followed by different letters at same ECw indicate significant difference by F test ($p \leq 0.05$)

Figure 5. Shoot dry matter of watermelon seedlings under different electrical conductivities of irrigation water (ECw) and substrates (SB)

Reduction in shoot dry matter of watermelon cv. Sugar Baby was reported by Ó et al. (2020), who irrigated the crop with increasing salinity (0.33, 1.5, 3.5, and 5.5 dS m^{-1}) and found a reduction of 39.4%. Silva Júnior et al. (2020), analyzing the same cultivar as the present study (Crimson Sweet) under salt stress, observed that the increase of ECw to 2.5 dS m^{-1} reduced the aboveground biomass by about 10%.

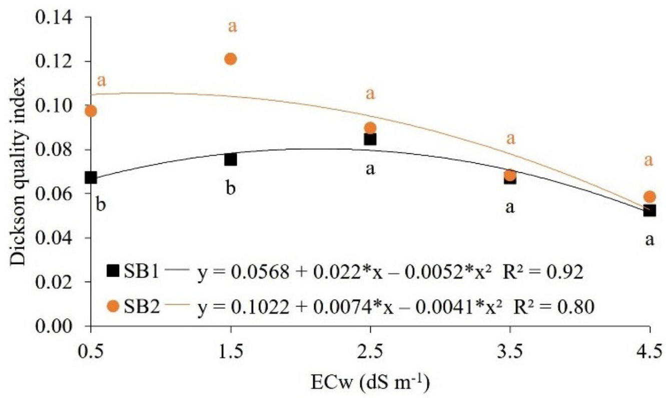
As observed in Figure 6A, the root dry matter of watermelon seedlings was reduced with the increase in ECw, and the data were described by a quadratic polynomial model, showing a maximum value of 0.25 g per plant for ECw of 1.48 dS m^{-1}.

The accumulation of salts in the substrate inhibited root development, due to the contact of the roots with the aqueous medium with high salt concentration, directly reducing its dry matter (Oliveira et al., 2019). When evaluating the emergence and initial development of pepper (*Capsicum frutescens*), Silva et al. (2021) reported a reduction in the length and root biomass of the crop with the salinity increment of 2.56 dS m^{-1}.

Total dry matter was reduced by 11.5% per unit increment of ECw and, according to the equation, the values corresponded to 0.48, 0.42, 0.36, 0.30, and 0.24 g per plant for conductivities of the irrigation water of 0.5, 1.5, 2.5, 3.5, and 4.5 dS m^{-1}, respectively (Figure 6B). This effect may be related to reduced synthesis of carbohydrates in seedlings and their accumulation in dry matter (Freire et al., 2018; Ó et al., 2020). Reduction in total dry matter was also reported by Santos et al. (2018), who evaluated the initial growth of three zucchini cultivars and linear decreases of 17.7, 38.5, and 33.7 mg per plant for each unit increase in water salinity for the genotypes Jacarezinho, Coroa, and the hybrid Tetsukabuto, respectively.

The Dickson quality index of watermelon seedlings under different ECw levels and two substrates showed a polynomial quadratic behavior (Figure 7). According to the equations, the maximum values found were 0.08, in seedlings that received irrigation with 2.11 dS m^{-1}, and 0.10, in seedlings irrigated with salinity of 2.0 dS m^{-1}, in substrates SB1 and SB2, respectively. Interaction analysis reveals that SB2 was significantly superior to SB1 at ECw of 0.5 and 1.5 dS m^{-1}, while at ECw of 2.5, 3.5, and 4.5 dS m^{-1} there was no significant effect on the Dickson quality index of watermelon seedlings (Figure 7).

Biochar, in turn, positively favors growth of seedlings in waters of low electrical conductivity, but still guarantees better results than the substrate with manure in all the evaluated ECw levels, because depending on the type and proportion of the organic compound in the substrate, its presence can impair root development by reducing macroporosity and, consequently, aeration and water supply in the substrate and the subsequent development of roots, thus affecting the development of the seedling, which is accentuated by the increase in the electrical conductivity of the irrigation water (Lisboa et al., 2018).



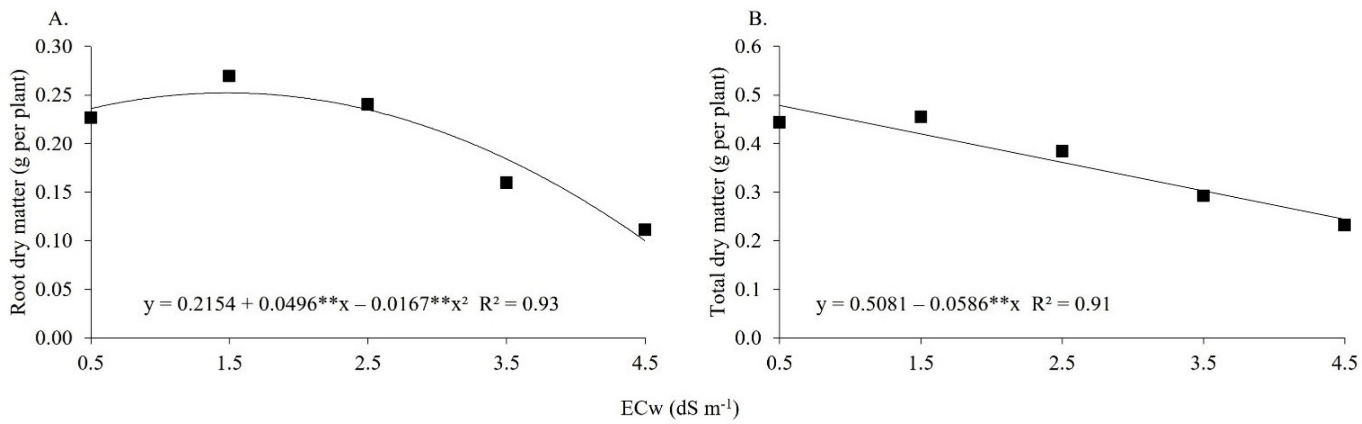
* Significant at $p \le 0.05$ by F test, respectively; SB1- Sandy soil + sand + bovine manure (1:1:1 - volume basis); and SB2 - Sandy soil + sand + biochar (1:1:1 - volume basis). Means followed by different letters at same ECw indicate significant difference by F test ($p \le 0.05$)

Figure 7. Dickson quality index of watermelon seedlings under different electrical conductivities of irrigation water (ECw) and substrates (SB)

Contrary to the present study, Alves et al. (2019) found that the use of organic input (bovine biofertilizer) did not affect the quality of seedlings of *Tamarindus indica* L.; however, with the increase in ECw levels from 0.5 dS m^{-1} there was a drop in seedling quality. Oliveira et al. (2015b), when evaluating the quality of watermelon seedlings at 31 DAS, in substrate with vermiculite + cassava branch + bovine manure (1:1:1 by volume), obtained DQI of 0.025 for the same cultivar as the present study (Crimson Sweet) in agricultural greenhouse.

Conclusions

1. The increase in the electrical conductivity of irrigation water from 1.5 dS m^{-1} reduces the percentage, speed index, and mean speed of emergence and increases the mean time of emergence of the watermelon seeds.



** - Significant at $p \le 0.01$ by F test, respectively

Figure 6. Root dry matter (A) and total dry matter (B) of watermelon seedlings under different electrical conductivities of irrigation water (ECw)

2. Substrate formulated with biochar reduces the mean time and increases the emergence indexes, besides enabling higher growth and biomass accumulation of watermelon seedlings.

3. Salt stress reduces the growth, biomass, and quality of watermelon seedlings, but with less intensity in substrate prepared with the addition of biochar.

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