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Induction of tolerance with salicylic acid in sour passion fruit irrigated with water of different cationic compositions

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Abstract

This study aimed to evaluate the physiological indices, growth, and seedling quality of the sour passion fruit cv. BRS SC1 as a function of irrigation with water of different cationic natures and exogenous application of salicylic acid. The experiment was conducted under plant nursery conditions at the CCTA/UFCG, Campus Pombal-PB, using a randomized block design set up in a 6 × 4 factorial arrangement referring to six cationic compositions of irrigation water (S_1 – control, S_2 - Na^+, S_3 - Ca^{2+}, S_4 - Na^+ + Ca^{2+}, S_5 - Mg^{2+}, and S_6 - Na^+ + Ca^{2+} + Mg^{2+}) and four concentrations of salicylic acid - SA (0, 1.0, 2.0, and 3.0 mM), with three replications and two plants per plot. In the control treatment (S_1), the plants were irrigated with the electrical conductivity level of 0.3 dS m^{-1}, whereas the other treatments (S_2, S_3, S_4, S_5, and S_6) used water with 4.0 dS m^{-1} obtained based on different cations, all in the form of chloride. The exogenous application of salicylic acid increased the content of chlorophyll *b* in the sour passion fruit seedlings. Salt stress negatively affected seedling growth. Seedling quality was affected by the electrical conductivity of irrigation water regardless of the cationic nature. Although showing reductions, the seedlings produced under high salinity showed a satisfactory Dickson quality index. The genotype cv. BRS SC1 is considered tolerant to salinity when irrigated with water salinized by Na^+, Ca^{2+}, Na^+ + Ca^{2+}, and Na^+ + Ca^{2+} + Mg^{2+}, and moderately tolerant when irrigated with water salinized by Mg^{2+}.

Keywords: mitigation, *Passiflora edulis* Sims, salt stress

Introduction

Sour passion fruit (*Passiflora edulis* Sims), a fruit species of the family Passifloraceae, is commercially grown in regions with tropical and semi-tropical climates (Lima et al., 2020). This crop stands out due to the outstanding quality of its fruits, which can be consumed fresh (*in natura*) or used to produce several by-products (Santos et al., 2017).

Brazil is the largest passion fruit producer and exporter worldwide, accounting in 2020 for 690,364 tons in an area of 46,530 hectares, with more than 70% of this production, or the equivalent of 491,326 tons, concentrated in the Northeast region of the country. In this scenario, the passion fruit production in the State of Paraíba accounted for 10,076 tons, with a mean yield of 9,607 kg ha^{-1}, which is still below the national mean yield of 14,867 kg ha^{-1} (IBGE, 2021).

Despite being considered a fruit species of significant importance to Northeastern Brazil, this region shows limitations for the expansion of irrigated agriculture due to low rainfall rates and high evapotranspiration, resulting in a water scarcity scenario that forces producers to use underground water sources with high salt contents (Veloso et al., 2018). Furthermore, the chemical nature of these water bodies is diversified and influenced by factors such as regional climatic conditions, the mineralogical composition of rocks, water residence time, and the underground water flow (Lima et al., 2016; Silva et al., 2018a; Lima et al., 2021a).

From this perspective, the deleterious effects caused by salinity on plants require alternatives capable of mitigating salt stress (Methenni et al., 2018), one of which is the foliar application of salicylic acid (SA). SA is a phenolic compound naturally produced by plants and involved in the signaling and activation of defense genes. It is also involved in the regulation of several physiological

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and biochemical processes such as germination, stomatal opening, transpiration, ionic absorption, and photosynthesis (Silva et al., 2018b; Silva et al., 2020).

Several studies have been developed to investigate the effects of salt stress on passion fruit (Bezerra et al., 2016, Moura et al., 2017, Silva et al., 2019, Bezerra et al., 2019; Lima et al., 2020a). However, these studies have been limited to crop performance evaluations under variable electrical conductivity levels and neglecting the possible effects caused by the different cations present in irrigation water.

From this perspective, this study aimed to evaluate the physiological indices, growth, and seedling quality of the passion fruit cultivar 'BRS SC1' as a function of irrigation with different cationic natures of water and foliar application of salicylic acid.

Material and Methods

The experiment was developed under plant nursery conditions from April to June 2021 at the Center of Sciences and Agrifood Technology (CCTA) of the Federal University of Campina Grande (UFCG), Campus Pombal-PB. The local geographic coordinates are 6°48'16" S and 37°49'15" W, at a mean elevation of 144 m above sea level.

The experiment was set up in a randomized block design with a 6 × 4 factorial arrangement whose treatments resulted from the combination of two factors: six cation compositions of irrigation water - CNW (S_1 - control; S_2 - Na^+; S_3 - Ca^{2+}; S_4 - $Na^+ + Ca^{2+}$; S_5 - Mg^{2+} and S_6 - $Na^+ + Ca^{2+} + Mg^{2+}$) and four concentrations of salicylic acid – SA (0, 1.0, 2.0, and 3.0 mM), with three replications. Each plot consisted of two plants, totaling 144 experimental units.

The irrigation water was prepared using an equivalent 1:1 proportion between Na:Ca and a 7:2:1 proportion between Na:Ca:Mg. The plants of the control treatment (S_1) were irrigated with the electrical conductivity level (ECw) of 0.3 dS m^{-1}, whereas the remaining water types (S_2; S_3; S_4; S_5 e S_6) were maintained with the ECw of 4.0 dS m^{-1}. The salicylic acid concentrations were established based on a study developed with soursop (Silva et al., 2020a).

The seeds used in this experiment belonged to the sour passion fruit cv. BRS SC1. The passion fruit seedlings were obtained by sowing three seeds per polyethylene bag measuring 15 × 30 cm and filled with a 2:1:1 proportion (based on volume) of a Psamment soil with a sandy-loam texture, sand, and organic matter (cattle manure) from the rural area of the municipality of São Domingos, PB, collected at a depth of 0-20 cm. Thinning was performed ten days after sowing (DAS) by maintaining only one plant per bag.

The water volume necessary to increase soil moisture to field capacity was determined before sowing by applying water according to the established treatments. After sowing, irrigation was performed daily at 5:00 p.m. by applying the water volume corresponding to the water balance in each bag, determined according to Eq. 1:

$$VI = \frac{(Va - Vd)}{(1 - LF)} \quad (1)$$

Where:

VI = Water volume to be used in the irrigation event (mL);

Va = Water volume applied in the previous irrigation event (mL);

Vd = Drained water volume (mL);

LF = 0.15 leaching fraction.

The physical and chemical soil characteristics were determined according to the methodology of Teixeira et al. (2017): Ca^{2+}, Mg^{2+}, Na^+, K^+, $Al^{3+} + H^+$ = 9.07; 2.78; 1.64; 0.23; 0.0; 8.61 $cmol_c\ kg^{-1}$, respectively; pH (water 1:2.5) = 5.58; ECse= 2.15 dS m^{-1}; organic matter= 0.293 dag Kg^{-1}; sand, silt, and clay = 57.27, 10.07, and 32.66 dag Kg^{-1}, respectively; P = 39.2 mg Kg^{-1}; SAR = 0.67 mmol L^{-1}; ESP = 7.34%; CEC = 22.33 $cmol_c\ Kg^{-1}$.

The irrigation water was obtained by adding Na^+, Ca^{2+}, and Mg^{2+} in the form of chloride according to the pre-established treatments and using the local tap water from Pombal-PB. The respective contents were determined by considering the relationship between the ECw and the concentration of salts (Richards, 1954) according to Eq. 2:

$$C = 640 \times ECw \quad (2)$$

Where:

C = Salt concentration to be added (mg L^{-1});

ECw = Water electrical conductivity (dS m^{-1}).

The concentrations of salicylic acid were prepared by diluting salicylic acid in 30% ethyl alcohol. The salicylic acid applications began 15 days after seedling emergence and were subsequently performed at 12-day intervals by spraying the plants until achieving full leaf wetting (abaxial and adaxial leaf surfaces) using a manual sprayer. The SA applications were performed at 5:00 p.m., and a plastic structure was used at the moment of each application to prevent drift on the plants of the other experimental plots.

Fertilization was performed according to the recommendations of Novais et al. (1991) by applying 100, 150, and 300 mg kg^{-1} of nitrogen, potassium, and phosphorus, respectively. Nitrogen was supplied as urea and monoammonium phosphate (MAP) and applied via irrigation water 15 and 30 days after sowing (DAS). Potassium fertilization was split into two applications (18 and 36 DAS) via fertigation at 10-day intervals using potassium chloride as a source (KCl). The micronutrient requirements were met through foliar spraying with a solution containing 0.5 g L^{-1} of Dripsol Micro Rexene® [(1.2% (Mg); 0.85 % (B); 3.4% (Fe); 4.2% (Zn); 3.2 % (Mn); 0.5% (Cu); 0.06% (Mo)] 15 and 30 days after emergence.

Plant growth was evaluated 60 days after sowing (DAS) by measuring the plant height (PH) from the ground to the insertion of the apical meristem; the stem diameter (SD), measured with a digital caliper at 5 cm from the soil and with the results expressed as mm; and the leaf area (LA), measured with a ruler after determining the length and width of the leaf blade according to Cavalcante et al. (2002) and following Eq. 3:

$$LA = \Sigma 0.81x \quad (3)$$

Where:
LA = leaf area (cm^2);
x = product of the length and width (cm^2).

The contents of chlorophyll and carotenoids were quantified by spectrophotometry at the absorbance wavelengths (ABS) of 470, 646, and 663 nm, according to Arnon (1949). Five leaf disk samples were collected from the blade of the third mature leaf, counting from the apex. The extracts were used to determine the concentrations of chlorophyll and carotenoids according to Eqs. 4, 5, and 6.

$$Chl\ a = 12.21\ ABS_{663} - 2.81\ ABS_{646} \quad (4)$$

$$Chl\ b = 20.13\ ABS_{646} - 5.03\ ABS_{663} \quad (5)$$

$$Car = (1000\ ABS_{470} - 1.82\ Chl\ a - 85.02\ Chl\ b)/198 \quad (6)$$

The values obtained for chlorophyll *a*, *b*, and carotenoids in the leaves were expressed as mg g^{-1} of fresh matter (mg g^{-1} FM).

Electrolyte leakage (EL) was determined in the leaf blade to evaluate the membrane disruptive ability under salt stress conditions according to Scotti-Campos et al. (2013) and using Eq. 7:

$$EL = \frac{Ci}{Cf} \times 100 \quad (7)$$

Where:
EL = Electrolyte leakage in the leaf blade (%);
Ci = Initial electrical conductivity (dS m^{-1});
Cf = Final electrical conductivity (dS m^{-1}).

For determining the leaf dry biomass (LDB), stem dry biomass (SDB), root dry biomass (RDB), and total dry biomass (TDP), the plants were collected, separated into different parts (leaf, stem, and root), and placed in kraft paper bags separated into subsamples, after which the material was oven-dried at 65°C for 48 hours. Next, the phytomass values were determined in a semi-analytical balance. The sum of the phytomass values of leaves, stems, and roots corresponded to the total phytomass.

The data on the growth variables were used to determine the Dickson quality index (DQI) according to Dickson et al. (1960) and using Eq. 8:

$$DQI = \frac{(TDP)}{(PH/SD) + (DPAP/RDB)} \quad (8)$$

Where:
DQI = Dickson quality index;
PH = plant height (cm);
SD = stem diameter (mm);
TDP = total dry biomass (g per plant);
DPAP = dry phytomass of aerial part (g per plant);
RDB = root dry biomass (g per plant).

The total dry biomass data were used to calculate the relative tolerance of sour passion fruit, and the genotype was classified with regard to salinity (Fageria & Gheyi, 1997) by adopting four classification levels: T (tolerant; 0-20%), MT (moderately tolerant; 20% - 40%), MS (moderately sensitive; 40% - 60%), and S (sensitive; > 60%). The percentage of loss was determined based on the total production per plant under the highest salinity (4.0 dS m^{-1}) compared to the lowest water salinity condition (0.3 dS m^{-1}).

The data obtained were evaluated through analysis of variance by the F-test. In cases of significance, Tukey's test ($p \leq 0.05$) was performed for the cationic nature of irrigation water, whereas polynomial regression ($p \leq 0.05$) was employed for the salicylic acid concentrations using the statistical software SISVAR-ESAL, version 5.6 (Ferreira, 2019).

Results and Discussion

There was no significant effect of the interaction between factors (NCA × SA) on electrolyte leakage (EL), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and carotenoids (Car) in the sour passion fruit cv. BRS SC1 60 DAS (Table 1). The cationic nature of water significantly affected electrolyte leakage and the contents of chlorophyll *a*, chlorophyll *b*, and carotenoids of the passion fruit seedlings. The salicylic acid concentrations only significantly affected the chlorophyll *b* content of the sour passion fruit seedlings.

Table 1. Summary of the analysis of variance referring to electrolyte leakage (EE), chlorophyll a (Chl *a*), chlorophyll b (Chl *b*), and carotenoids (Car) of the sour passion fruit cv. BRS SC1 irrigated with water of different cationic natures and exogenous application of salicylic acid 60 days after sowing (DAS).

Source of variation	DF	Mean squares			
		EL	Chl *a*	Chl *b*	Car
Cationic nature of water - CNW	5	114.41**	122.38**	8.12**	9.17**
Salicylic acid (SA)	3	6.33ns	7.58ns	5.95*	0.94ns
Linear regression	1	3.96ns	1.28ns	9.94ns	0.09ns
Quadratic regression	1	14.10ns	2.01ns	1.93ns	0.41ns
Interaction (CNW × SA)	15	3.57ns	13.60ns	2.71ns	1.40ns
Blocks	2	81.32ns	26.38ns	5.37ns	1.63ns
Residue	46	9.75	9.96	1.75	0.86
CV (%)	-	20.80	26.89	34.28	24.81

DF – Degree of freedom; CV – Coefficient of variation; (*) significant at 0.05; (**) significant at 0.01 of probability; (ns) non-significant.

The highest electrolyte leakage percentage - EL (Figure 1A) was observed when the plants were irrigated with water salinized by Ca^{2+} (S_3). However, these plants did not differ from those irrigated with the combination of Na^+ + Ca^{2+} (S_4). The lowest EL percentage (9.87%) was achieved when the plants received low-salinity water (S_1), statistically differing from the other treatments (Na^+, Ca^{2+}, Na^+ + Ca^{2+}, Mg^{2+} and Na^+ + Ca^{2+} Mg^{2+}). When comparing the values of the different cationic natures, the control treatment was 33.75, 48.88, 40.07, 30.83, and 35.23% lower than the mean value obtained with treatments S_2, S_3, S_4, S_5, and S_6, respectively.

The increase in electrolyte leakage with the increase in the ECw can be related to the ionic effect of salts since their concentration in the root zone can change the nutrient balance, including calcium availability (Ferraz et al. 2015, Salazar et al., 2017), which is essential for cell wall formation (Wanderley et al., 2020). Furthermore, the abundant K^+ efflux in the plant cells favors the intensification of lipid peroxidation caused by reactive oxygen species, consequently altering cell homeostasis and resulting in membrane instability (Hnilicková et al., 2019; Sharma et al., 2012).

Lima et al. (2021b) evaluated the effects of irrigation water salinity (0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}) prepared with NaCl on the formation of sour passion fruit seedlings and also observed an increase in electrolyte leakage in the leaf blade, with a 16.82% increase in the plants irrigated with 3.5 dS m^{-1} in relation to those grown under the lowest salinity level (0.3 dS m^{-1}).

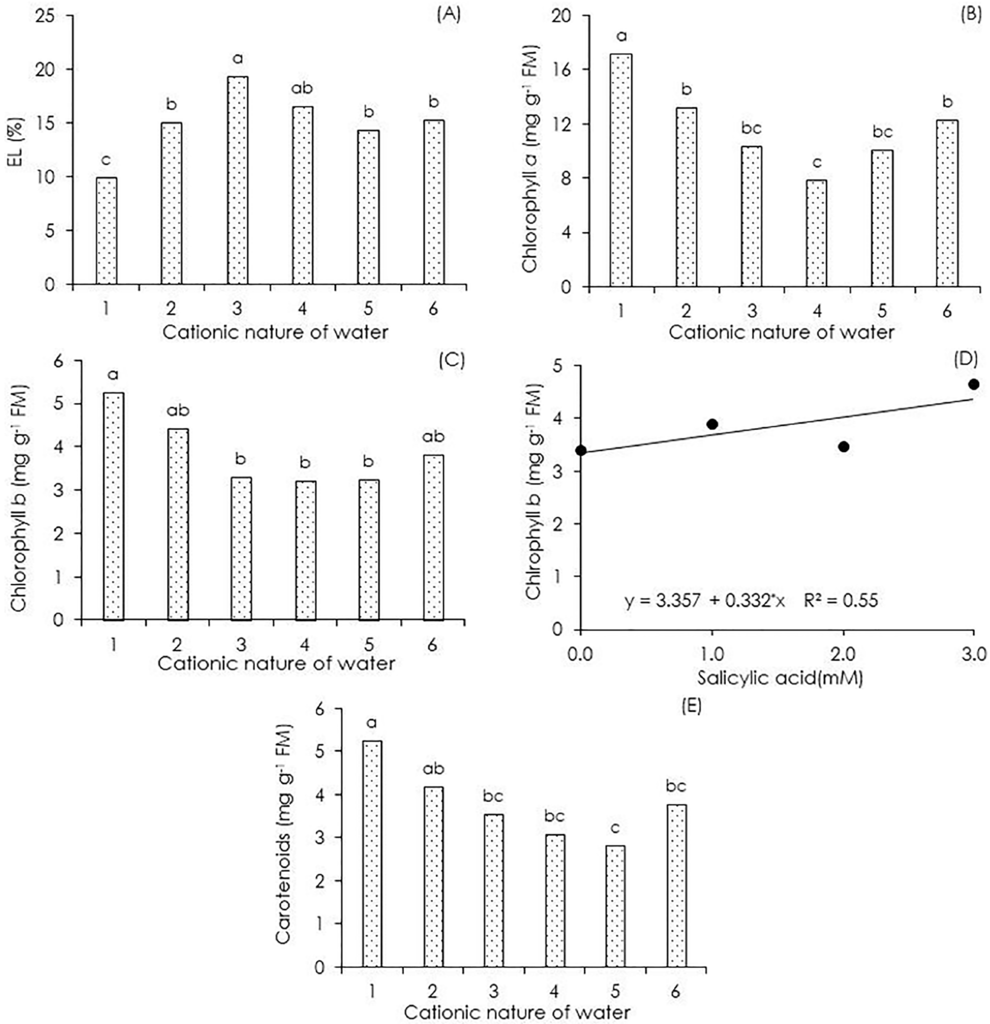
The highest content of chlorophyll *a* (Figure 1B) (17.06 mg g^{-1} FM) was obtained when the plants were irrigated with the lowest salinity level (control), statistically higher than the other treatments (S_2, S_3, S_4, S_5, and S_6). Conversely, the lowest content of chlorophyll *a* (7.84 mg g^{-1} FM) was obtained when the plants were subjected to the salinity of the Na^+ + Ca^{2+} composition (S_4), not differing significantly from the treatments composed of Ca^{2+} (S_3) and Mg^{2+} (S_5), which showed mean values of 10.24 and 9.97 mg g^{-1} FM, respectively.

The cationic nature of irrigation water also significantly affected the contents of chlorophyll *b* (Figure 1C), showing the highest value (5.24 mg g^{-1} FM) in the plants irrigated with the ECw of 0.3 dS m^{-1} (control) and differing statistically from the plants grown under the water salinity composed of Ca^{2+} (S_3), Na^+ + Ca^{2+} (S_4), and Mg^{2+} (S_5). There were no significant differences when comparing the plants subjected to different cationic natures (S_2, S_3, S_4, S_5, and S_6).

The reduction in chlorophyll synthesis under water salinity conditions could be related to the increase in chlorophyllase activity, which degrades chlorophyll and negatively affects plants under salt stress. Furthermore, there may occur induction and degradation of ß-carotene, limiting the formation of zeaxanthin (Lima et al., 2004). At high levels, salinity can cause damage to chloroplasts and thus compromise the activity of pigmentation proteins (Freire et al., 2013).

The foliar application of salicylic acid linearly increased the chlorophyll *b* contents of sour passion fruit (Figure 1D) at a rate of 0.988% per 1.0 mM increase in SA. A 26.88% increase is observed when comparing the chlorophyll *b* values of the plants subjected to 3.0 mM against those of the control treatment (0 mM). The increase in chlorophyll *b* with the increase in salicylic acid observed in this study could be related to the beneficial effects of SA since, in addition to being a natural signaling molecule for the activation of plant defense mechanisms, SA also modifies the antioxidant system by stimulating the action of enzymes such as superoxide dismutase, catalase, and peroxidase (Sharma & Bhardwaj, 2014).

For the contents of carotenoids (Figure 1E), the plants irrigated with low electrical conductivity (Control) were statistically superior to those that received the cationic water composed of Ca^{2+} (S_3), Na^+ + Ca^{2+} (S_4), Mg^{2+} (S_5), and Na^+ + Ca^{2+} + Mg^{2+} (S_6), although not differing statistically from those irrigated with the water salinized by sodium (S_2). The lowest carotenoid contents were observed in the plants cultivated with water salinized by Mg^{2+} (S_5) (2.81 mg g^{-1} FM), significantly differing from the control (S_1) and Na^+ (S_2) treatments.



1 - Control; 2 - Na^+; 3 - Ca^{2+}; 4 - Na^+ + Ca^{2+}; 5 - Mg^{2+}; 6 - Na^+ + Ca^{2+} + Mg^{2+}. Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$).

Figure 1. Electrolyte leakage - EL (A), chlorophyll *a* – Chl *a* (B), chlorophyll *b* – Chl *b* (C and D), and carotenoids (E) of the sour passion fruit cv. BRS SC1 as a function of the cationic nature of water and salicylic acid concentrations (E) 60 days after sowing (DAS).

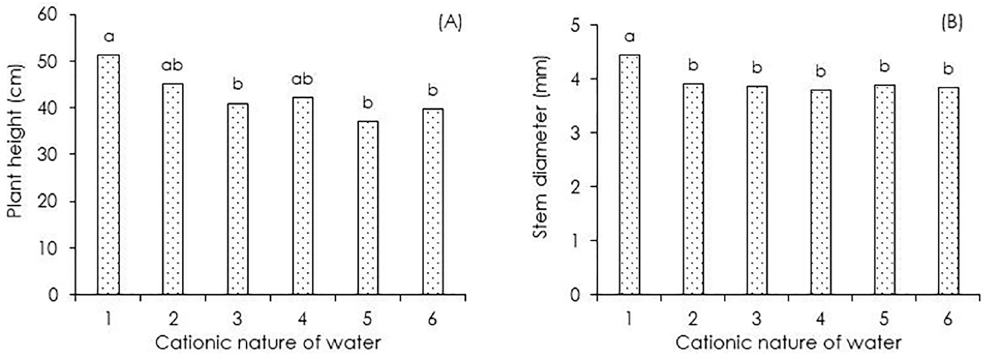
There was no significant effect of the interaction between factors (CNW × SA) on plant height (PH), stem diameter (SD), and leaf area (LA) of passion fruit plants (Table 2). The cationic nature of irrigation water (CNW) significantly influenced plant height and stem diameter in sour passion fruit plants. The salicylic acid concentrations had no significant effect on plant height, stem diameter, and leaf area of the sour passion fruit cv. BRS SC1 60 days after sowing (DAS).

The sour passion fruit plants irrigated with low-salinity water (Test) showed plant height values (51.22 cm) statistically higher than those irrigated with water salinized by Ca^{2+} (S_3), Mg^{2+} (S_5), and the mixture of Na^+ + Ca^{2+} + Mg^{2+} (S_6), reaching 40.91, 32.02, and 39.64 cm, respectively (Figure 2A). However, there were no significant differences between the control treatment with the plants that received water salinized by Na^+ (S_2) and the mixture of Na^+ + Ca^{2+} (S_4).

Table 2. Summary of the analysis of variance referring to plant height (PH), stem diameter (SD), and leaf area (LA) of the sour passion fruit cv. BRS SC1 irrigated with water of different cationic natures and exogenous application of salicylic acid 60 days after sowing (DAS).

Source of variation	DF	Mean squares		
		PH	SD	LA
Cationic nature of water - CNW	5	295.42**	0.71**	12867ns
Salicylic acid (SA)	3	4.84ns	0.08ns	4194.31ns
Linear regression	1	3.02ns	0.25ns	12266.22ns
Quadratic regression	1	10.50ns	0.01ns	308.96ns
Interaction (CNW × SA)	15	97.51ns	0.09ns	7162.40ns
Blocks	2	142.12ns	0.08ns	22915.21ns
Residue	46	70.93	0.07	11249.22
CV (%)	-	19.74	6.95	12.60

DF- degree of freedom; CV (%) – coefficient of variation; *significant at 0.05 of probability; ** significant at 0.01 of probability; ns non-significant.



1 - Control; 2 - Na^+; 3 - Ca^{2+}; 4 - $Na^+ + Ca^{2+}$; 5 - Mg^{2+}; 6 - $Na^+ + Ca^{2+} + Mg^{2+}$. Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$).

Figure 2. Plant height (A) and stem diameter (B) of the sour passion fruit cv. BRS SC1 irrigated with water of different cationic natures 60 days after sowing (DAS).

For stem diameter (SD), the plants irrigated with 0.3 dS m^{-1} (S_1) stood out with the highest SD growth, which was statistically superior to the other treatments (S_2, S_3, S_4, S_5, and $S_{6)}$ (Figure 2B). There were DC increases of 0.54, 0.59, 0.65, 0.57, and 0.61 mm in the plants irrigated with low-salinity water (S_1) in relation to treatments S_2, S_3, S_4, S_5, and S_6, respectively. There was no significant difference between the different cationic natures of irrigation water (S_2, S_3, S_4, S_5, and S_6), which achieved the mean values of 3.9, 3.85, 3.79, 3.87, and 3.83 mm, respectively.

The growth reduction observed in this study could be related to the osmotic effect promoted by the increased ECw, which limited water and nutrient uptake by plants, affecting processes such as photosynthesis and protein synthesis. Furthermore, the tension caused by water salinity reduced the production of plant hormones involved in cell division, thus compromising plant growth (Kozminska et al., 2017). Paiva et al. (2021) evaluated the effects of irrigation with different cationic water compositions ((S_1 - control (0.4 dS m^{-1}); S_2 - Na^+; S_3 - Ca^{2+}, S_4 - Mg^{2+}; S_5 - $Na^+ + Ca^{2+}$, S6 - $Na^+ + Mg^{2+}$, S_7 - $Ca^{2+} + Mg^{2+}$, and S_8 - $Na^+ + Ca^{2+} + Mg^{2+}$) in sour passion fruit cultivation and also observed stem diameter reductions regardless of the cationic nature 90 and 180 days after transplanting.

The interaction between factors (CNW × SA) significantly affected the dry root phytomass (RDB) of sour passion fruit plants (Table 3). The cationic nature of water significantly affected the accumulation of dry leaf phytomass (LDB) and the dry stem phytomass (SDB). The salicylic acid concentrations did not significantly affect phytomass accumulation in the sour passion cv. BRS SC1 60 DAS.

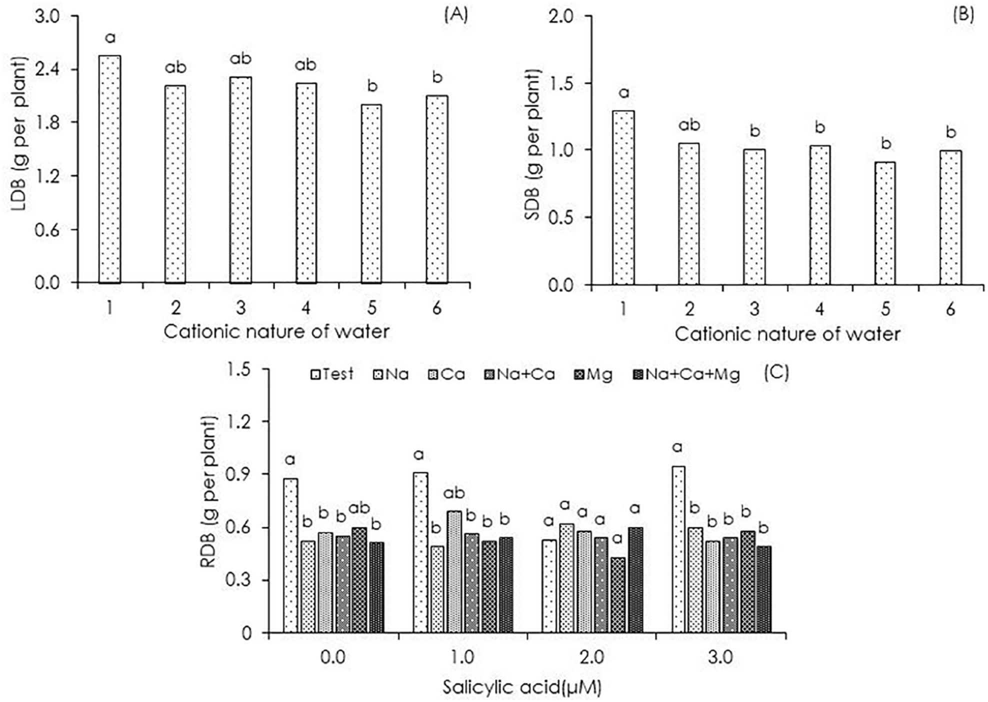
For the leaf dry biomass of sour passion fruit plants (Figure 3A), irrigation with low-salinity water (Test) resulted in the highest value of this variable (2.54 g per plant), which was statistically higher than the values obtained when using water salinized by Mg^{2+} (S_5) and the $Na^+ + Ca^{2+} + Mg^{2+}$ composition (S_6). There were no significant differences in the FSF of the plants subjected to irrigation with Na^+ (S_2), Ca^{2+} (S_3), and $Na^+ + Ca^{2+}$ (S_4).

For the stem dry biomass (Figure 3B), the plants irrigated with low-salinity water (Test) showed the highest value for this variable (1.29 g per plant), differing statistically from the other treatments (S_3, S_4, S_5, and S_6), except for the plants that received water salinized by Na^+ (S_2), whose mean value was 1.05 g per plant. Moreover, there was no statistical difference between the plants subjected to the water salinity of the sodium composition (S_2) in relation to the other cationic concentrations (S_3, S_4, S_5, and S_6).

Table 3. Summary of the analysis of variance referring to the leaf dry biomass (LDB), stem dry biomass (SDB), and root dry biomass (RDB) of the sour passion fruit cv. BRS SC1 irrigated with water of different cationic natures and exogenous application of salicylic acid 60 days after sowing (DAS).

Source of variation	DF	Mean squares		
		LDB	SDB	RDB
Cationic nature of water - CNW	5	0.41^{**}	0.19^{**}	0.14^{**}
Salicylic acid (SA)	3	0.04^{ns}	0.01^{ns}	0.01^{ns}
Linear regression	1	0.005^{ns}	0.01^{ns}	0.001^{ns}
Quadratic regression	1	0.0001^{ns}	0.001^{ns}	0.009^{ns}
Interaction (CNW × SA)	15	0.04^{ns}	0.04^{ns}	0.02^{*}
Blocks	2	0.06^{ns}	0.04^{ns}	0.001^{ns}
Residue	46	0.07	0.04	0.01
CV (%)		12.36	19.45	20.13

GL- degree of freedom; CV (%) – coefficient of variation; *Significant at 0.05 of probability; ** Significant at 0.01 of probability; ns non-significant.



1 - Control; 2 - Na^{+}; 3 - Ca^{2+}; 4 - Na^{+} + Ca^{2+}; 5 - Mg^{2+}; 6 - Na^{+} + Ca^{2+} + Mg^{2+}. Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$).

Figure 3. Leaf dry biomass – LDB (A), stem dry biomass – SDB (B), and root dry biomass – RDB (C) of the sour passion fruit cv. BRS SC1 as a function of the cationic nature of water and salicylic acid concentrations 60 days after sowing.

The decrease in dry stem phytomass accumulation could be related to the osmotic effect caused by excess salts in the water, altering the ionic and osmotic homeostasis and causing growth reductions, consequently resulting in reduced phytomass accumulation (Sá et al. 2019). Lima et al. (2021b) evaluated the effects of water salinity prepared with NaCl (ECw: 0.3 to 3.5 dS m^{-1}) on the formation of sour passion fruit seedlings and observed reductions in the accumulation of leaf dry biomass and stem dry biomass as the electrical conductivity of irrigation water increased.

For the root dry biomass (Figure 3C), the unfolding of the interaction between factors (CNW × SA) shows that, in the absence of foliar SA (0 mM), the sour passion fruit plants irrigated with low-salinity water (S_1) and with the Mg^{2+} composition (S_5) stood out with the highest LDB values in relation to the other treatments (S_2, S_3, S_4, S_6). The most expressive LDB values were recorded when the plants received 1.0 mM SA and were irrigated with low ECw levels (S_1) and calcium (S_3). However, there was no significant difference in the LDB between different cationic natures of water for this concentration. Moreover, there was no significant difference in the LDB in the plants subjected to 2.0 mM salicylic acid regardless of the cationic nature of water. On the other hand, the plants subjected to 3.0 mM SA and irrigated with the lowest ECw level (S_1) showed a statistically higher LDB accumulation in relation to the plants cultivated under S_2, S_3, S_4, S_5 and S_6.

These results show that the beneficial effect of SA was only highlighted when low-salinity water was used

(0.3 dS m^{-1}), with no satisfactory results when using 4.0 dS m^{-1}. This result is possibly due to the time of exposure to salicylic acid since no adhesive spreader was used at the moment of application, possibly resulting in the loss of acid through volatilization and/or runoff on the leaves. According to Poór et al. (2017), in order for sufficient accumulation to occur and for the plant to signal and activate enzymes that act in the antioxidant system, the time of exposure to SA after foliar application should be approximately 12 hours. Moreover, the exogenous application of SA not always provides satisfactory results on plant growth since the effects may vary according to each species (El-Esawi et al., 2017; Farhangi-Abriz & Ghassemi-Golezani, 2018).

There was no significant effect of the interaction between factors (CNW × SA) on the total dry biomass (TDP) and the Dickson quality index (DQI) of sour passion fruit plants (Table 4). The cationic nature of water influenced the TDP and DQI of the sour passion fruit cv. BRS SC1 60 DAS. There was no significant effect of the salicylic acid concentrations on the TDP and DQI of the plants.

The plants irrigated with the lowest ECw (test) showed the highest accumulation of total dry biomass (4.40 g per plant). However, these plants did not differ statistically from those irrigated with 4.0 dS m^{-1} of the cationic composition formed by Na^+ (S_2), Ca^{2+} (S_3), and the mixture of $Na^+ + Ca^{2+}$ (S_4), which resulted in the values of 3.83, 3.89, and 3.81 g per plant, respectively.

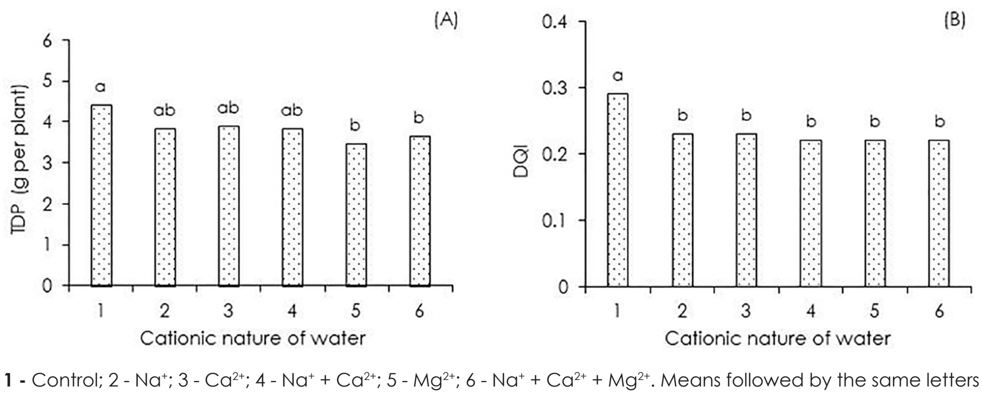
For the Dickson quality index (Figure 4), the plants irrigated with the lowest salinity level (Test) had a statistically higher DQI compared to the other treatments (S_2, S_3, S_4, S_5, and S_6). The plants grown under the lowest water salinity (Test) had a DQI higher by 0.06, 0.06, 0.07, 0.07, and 0.07 in relation to those grown with compositions Na^+ (S_2), Ca^{2+} (S_3), $Na^+ + Ca^{2+}$ (S_4), Mg^{2+} (S_5), and $Na^+ + Ca^{2+} + Mg^{2+}$ (S_6), respectively.

Although the values obtained by the plants irrigated with the ECw = 4.0 dS m^{-1} (S_2, S_3, S_4, S_5, and S_6) were statistically lower than those obtained in the plants irrigated with the low ECw (S_1), the plants that received the highest salinity level obtained an acceptable DQI, which, according to et al. (1960) should be at least 0.20.

Table 4. Summary of the analysis of variance referring to the total dry biomass (TDP) and Dickson quality index (DQI) of the sour passion fruit cv. BRS SC1 irrigated with different cationic natures of water and exogenous application of salicylic acid 60 days after sowing.

Source of variation	DF	Mean squares	
		TDP	DQI
Cationic nature of water - CNW	5	1.244**	0.008*
Salicylic acid (SA)	3	0.188ns	0.0004ns
Linear regression	1	0.000ns	0.0002ns
Quadratic regression	1	0.437ns	0.0010ns
Interaction (CNW × SA)	15	0.371ns	0.003ns
Blocks	2	0.0177ns	0.003ns
Residue	46	0.237	0.001
CV (%)	-	12.72	18.22

DF - degree of freedom; CV (%) – coefficient of variation; *significant at 0.05 of probability; ** significant at 0.01 of probability; ns non-significant.



1 - Control; 2 - Na^+; 3 - Ca^{2+}; 4 - $Na^+ + Ca^{2+}$; 5 - Mg^{2+}; 6 - $Na^+ + Ca^{2+} + Mg^{2+}$. Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$).

Figure 4. Total dry biomass - TDP (A) and Dickson quality index - DQI (B) of the sour passion fruit cv. BRS SC1 as a function of different cationic natures of water 60 days after sowing.

The reduction in the accumulation of Total dry biomass in the plants irrigated with the ECw = 4.0 dS m^{-1} and salinized by Na^+, Ca^{2+}, $Na^+ + Ca^{2+}$, Mg^{2+}, and $Na^+ + Ca^{2+} + Mg^{2+}$ was the equivalent to 12.96, 11.60, 13.41, 21.82, and 17.50%, respectively, in relation to the plants that received low-salinity water (ECw = 0.3 dS m^{-1}). Based on the relative yield, the sour passion fruit cv. BRS SC1 can be classified as tolerant when irrigated with the ECw = 4.0 dS m^{-1} and salinized by Na^+, Ca^{2+}, $Na^+ + Ca^{2+}$, and the mixture of $Na^+ + Ca^{2+} + Mg^{2+}$ (reduction of < 20%) and classified as moderately tolerant when irrigated with ECw = 4.0 dS m^{-1} and salinized by Mg^{2+} (reduction of 20 – 40%).

Conclusions

Irrigation with the electrical conductivity level of 4.0 dS m^{-1} increases electrolyte leakage in the leaf blade of the sour passion fruit cv. BRS SC1 regardless of the cationic nature 60 days after sowing;

The exogenous application of salicylic acid increased the synthesis of chlorophyll *b* in the seedlings of the sour passion fruit cv. BRS SC1;

The growth of sour passion fruit seedlings is negatively affected by salt stress regardless of the cationic nature of irrigation water 60 DAS;

Despite showing reductions, the seedlings produced under the salinity of 4.0 dS m^{-1} show acceptable quality and can be used for transplanting to the field.

The genotype cv. BRS SC1 is considered tolerant when irrigated with water salinized by Na^+, Ca^{2+}, $Na^+ + Ca^{2+}$, and $Na^+ + Ca^{2+} + Mg^{2+}$, and moderately tolerant when irrigated with waters salinized by Mg^{2+}.

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