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Tolerance of sour passion fruit cultivars to salt stress in a semi-arid region[1]

Tolerância de cultivares de maracujazeiro-azedo ao estresse salino numa área semiárida

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HIGHLIGHTS:
Electrical conductivity of water from 0.3 dS m^{-1} decreases the relative water content and limits gas exchange.
The production of sour passion fruit cultivars is markedly reduced by electrical conductivity of water above 0.3 dS m^{-1}.
The BRS GA1, BRS SC1, and SCS437 sour passion fruit cultivars grown in a semi-arid region are sensitive to salt stress.

ABSTRACT: Given the quantitative scarcity of low-salinity water resources in the Brazilian semi-arid region, it is necessary to use water with a high concentration of salts. Thus, identifying salt-stress tolerant cultivars of crops is an alternative for expanding irrigated agriculture. The objective of this study was to evaluate the tolerance of passion fruit cultivars as a function of irrigation water electrical conductivity. The experimental design was randomized blocks, in a 5 × 3 factorial scheme, whose treatments consisted of the combination of five values of electrical conductivity of irrigation water - ECw (0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}) and three sour passion fruit cultivars (BRS GA1, BRS SC1, and SCS437, with three replicates. Electrical conductivity of water from 0.3 dS m^{-1} reduces the relative water content, gas exchange, and the number of fruits and increased electrolyte leakage in the leaf blade of passion fruit plants, at 153 days after transplantation. The passion fruit cultivars BRS GA1, BRS SC1, and SCS437 were classified as sensitive, with threshold electrical conductivity of water of 0.3, 1.0, and 0.3 dS m^{-1}, respectively.

Key words: *Passiflora edulis* Sims, water scarcity, semi-arid region

RESUMO: Diante da escassez quantitativa de recursos hidrícos de baixa salinidade no semiárido do brasileiro, fez-se necessário a utilização de águas com alta concentração de sais. Assim, a identificação de cultivares tolerantes ao estresse salino é uma alternativa para expansão da agricultura irrigada. Neste contexto, objetivou-se com este trabalho avaliar a tolerância de cultivares de maracujazeiro-azedo em função da condutividade elétrica da água de irrigação. O delineamento experimental foi em blocos ao acaso, em esquema fatorial 5 × 3, cujos tratamentos consistiram da combinação de cinco valores de condutividade elétrica da água de irrigação - CEa (0,3; 1,1; 1,9; 2,7 e 3,5 dS m^{-1}), e três genótipos de maracujazeiro-azedo (BRS GA1, BRS SC1 e SCS437), com três repetições. A condutividade elétrica da água a partir de 0,3 dS m^{-1} diminuiu o conteúdo relativo de água, as trocas gasosas, o número de frutos, a produção por planta e aumentou o extravasamento de eletrólitos no limbo foliar das plantas de maracujazeiro-azedo, aos 153 dias após o transplantio. As cultivares de maracujazeiro-azedo BRS GA1, BRS SC1 e SCS437 foram classificadas como sensíveis à condutividade elétrica da água, com os níveis de salinidade limiar de 0,3; 1,0 e 0,3 dS m^{-1}, respectivamente.

Palavras-chave: *Passiflora edulis* Sims, escassez hídrica, semiárido

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Introduction

Sour passion fruit (*Passiflora edulis* Sims) is a tropical fruit crop grown from North to South of Brazil, and stands out due to the physicochemical quality of the fruits and the consumer's acceptance (Paiva et al., 2021). The cultivation of this fruit crop in the semi-arid region of Northeastern Brazil, due to the imbalance between precipitation and evapotranspiration rates, is dependent on irrigation management, but the quality of water sources is one of the limiting factors, as the levels of salts are usually high, both in surface water and in groundwater (Pinheiro et al., 2022; Souto et al., 2023).

Excess salts in water and, or, soil reduce water availability due to osmotic and ionic effects (Bezerra et al., 2018). Under salt stress conditions, plants accumulate sodium (Na^+) and chloride (Cl^-) ions, which are responsible for physiological and biochemical changes, including the production of reactive oxygen species (ROS), which degrade photosynthetic pigments and cause lipid peroxidation of the membrane, denaturation of proteins, and mutation in nucleic acids (Kotagiri & Kolluru, 2017).

However, the intensity with which salt stress affects plants depends on factors such as cultivar, type of soil, intensity and duration of stress, crop and irrigation management, edaphoclimatic conditions, and fertilization (Soares et al., 2018; Lima et al., 2023). Lima et al. (2021a) in a study evaluating the effects of irrigation with saline water (ECw ranging from 0.3 to 3.5 dS m^{-1}) on the tolerance of a cultivar and an accession of sour passion fruit (BRS Sol do Cerrado and Guinezinho), found that BRS Sol do Cerrado and Guinezinho is sensitive to water salinity from 0.3 dS m^{-1}.

Thus, the identification of salt stress-tolerant sour passion fruit cultivars stands out as an important strategy for the management of irrigation with saline water, especially in semi-arid regions. The objective of this study was to evaluate the tolerance of passion fruit cultivars as a function of irrigation water salinity.

Material and Methods

The study was conducted from January to July 2022 in 100-L pots adapted as drainage lysimeters under open field conditions in the experimental area belonging to the 'Rolando Enrique Rivas Castellón' Farm at the Centro de Ciências e Tecnologia Agroalimentar - CCTA of the Universidade Federal de Campina Grande - UFCG, in São Domingos, Paraíba, Brazil, located by the coordinates: 06° 48' 50" S latitude and 37° 56' 31" W longitude, at altitude of 190 m. The climate of the municipality is characterized as semi-arid tropical (BSh) and has an average annual rainfall of 700 mm (Alvares et al., 2013). Maximum and minimum temperature, relative air humidity, and precipitation data are shown in Figure 1.

The experimental design of randomized blocks was used in a 5 × 3 factorial scheme, and the treatments were obtained by combining five values of electrical conductivity of irrigation water - ECw (0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}) and three cultivars of sour passion fruit - CUL (BRS GA1, BRS SC1, and SCS437), with three replicates and one plant per experimental unit. The ECw values were based on a study conducted with sour passion fruit by Lima et al. (2021b), who observed that irrigation water with an electrical conductivity of up to 3.5 dS m^{-1} can be used to form passion fruit seedlings with acceptable quality for transplantation to the field.

Seeds of sour passion fruit BRS GA1, BRS SC1, and SCS437 were used. Seeds were acquired from a commercial agricultural product store. Sowing was performed by placing two seeds in each polyethylene plastic bag with dimensions of 15 × 20 cm, filled with substrate, consisting of a mixture (volume basis) of 84% of soil, 15% of washed sand and 1% of organic compost (earthworm humus). After seedling emergence, thinning was performed, leaving only one plant per container when they were 10 cm tall. When the plants started producing tendrils, they were transplanted to the lysimeters.

Plastic pots with capacity of 100 L adapted as drainage lysimeters were used. At the bottom of each lysimeter, a drain with diameter of 16 mm was installed to remove excess water and connected to a container to collect the drained water, which

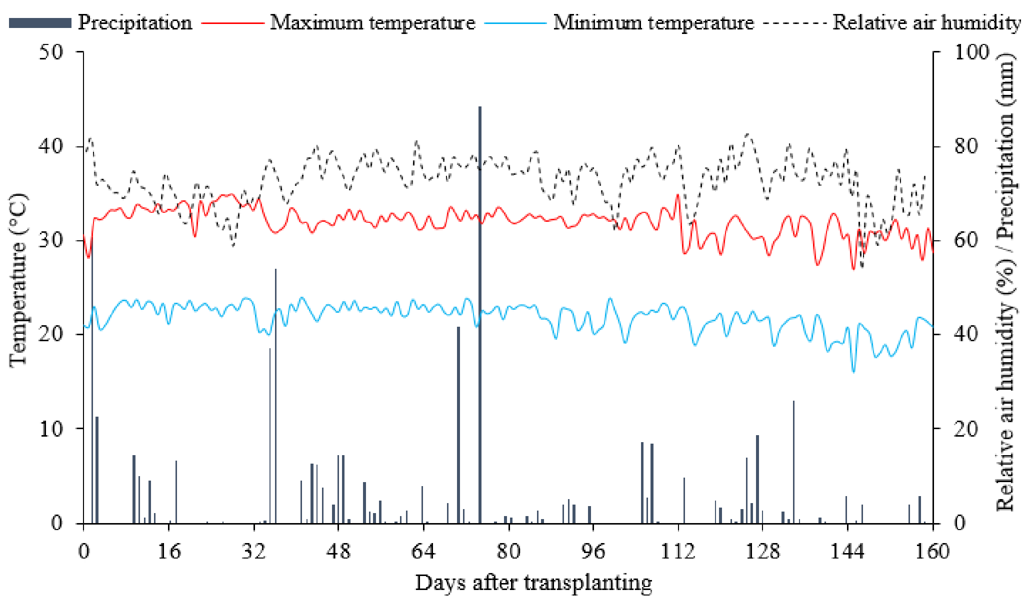


Figure 1. Precipitation, maximum and minimum air temperature, and relative air humidity during the experimental period

subsequently allowed determining the water consumption by the plants. The end of the drain inside the pot was wrapped with a non-woven geotextile blanket (Bidim OP 30) to avoid obstruction by soil material.

The lysimeters were filled with 0.5 kg layer of crushed stone on the Bidim of each drain, followed by a 100 kg layer of soil from the experimental area of CCTA/UFCG in São Domingos - PB. The soil of the experimental area was classified as Entisol (United States, 2014), which corresponds to Neossolo Flúvico Ta Eutrófico típico of sandy loam texture in the Brazilian soil classification system, whose chemical (soil fertility) and physical attributes (Table 1) were obtained according to the methodologies proposed by Teixeira et al. (2017).

The seedlings were kept with the collar region, a region of transition between the root system and the stem, at ground level, to avoid deepening. Phosphorus fertilization was performed all at once, incorporated to the soil in the filling of lysimeters, using 50 g of single superphosphate (17% P_2O_5; 16% Ca^{2+}; 8% S), while fertilization with nitrogen and potassium was applied as top-dressing at monthly intervals. 65 g of K_2O per plant was applied in the crop formation stage (vegetative stage) and 280 g of K_2O per plant was applied in the flowering and fruiting stages, as recommended by Costa et al. (2008). Urea (45% N) and potassium sulfate (50% K_2O and 17.5% S) were used as sources of nitrogen and potassium, respectively. The micronutrients were provided through the leaves, as indicated by Costa (2008), maintaining the concentrations of zinc (4.0 g L^{-1}), copper (1.5 g L^{-1}), boron (2.0 g L^{-1}), iron (1.5 g L^{-1}), and manganese (3.0 g L^{-1}). Zinc sulfate (20% Zn), iron sulfate (20% Fe), boric acid (17% B), and manganese sulfate (30% Mn) were used as sources of zinc, iron, boron, and manganese, respectively.

After being transplanted to the lysimeters, the plants were guided using nylon strings to conduct them upright up to the trellis height (1.20 m). Frequent thinning was performed until the plants reached the trellis height when they were then trained appropriately. The plants were grown with a single stem. At 15 days after transplanting the plants, formative pruning began to be performed, eliminating all lateral shoots and leaving only the main stem, which was guided by a stake until reaching the support wire.

The spacing used was 3 m between rows and 3 m between plants considering the center of lysimeters, using the vertical trellis system (1.20 m height). Twine was used to guide the plant to the trellis. When the plants reached 10 cm above the trellis, the apical bud was pruned to stimulate the emergence of the two secondary branches, which were grown one to each side up to 1.5 m length. After the secondary branches reached this length the apical bud was pruned again to stimulate the emergence of the tertiary branches, which were grown to 30 cm from the soil. Throughout the experiment, tendrils and unwanted branches were eliminated, aiming to favor the development of the crop.

The water used in the irrigation of the treatment of the lowest electrical conductivity (control - 0.3 dS m^{-1}) came from an artesian well located in the experimental area of CCTA/UFCG, while the other ECw values were prepared by the dissolution of NaCl in the supply water. The irrigation water was prepared considering the relationship between ECw and salt concentration (Richards, 1954), according to Eq. 1, used to prepare waters in the laboratory:

$$Q \approx 640 \times ECw \quad (1)$$

where:
Q - quantity of salts to be applied (mg L^{-1}); and,
ECw - electrical conductivity of water (dS m^{-1}).

Prior to transplanting, the volume of water needed to raise the moisture content to the corresponding level of field capacity was determined, applying water according to the treatments. Subsequently, irrigation was performed daily at 5 p.m., applying the volume corresponding to that obtained by water balance in each lysimeter (Paiva et al., 2021), with the volume of water to be applied determined by Eq. 2:

$$VI = \frac{(Va - Vd)}{(1 - LF)} \quad (2)$$

where:
VI - volume of water to be applied (mL);
Va - volume applied in the previous irrigation event (mL);
Vd - volume of water drained (mL); and,
LF - leaching fraction (0.15).

At 153 days after transplanting (DAT), the following variables were evaluated: relative water content (RWC), electrolyte leakage (% EL), and gas exchange by stomatal conductance - gs (mol H_2O m^{-2} s^{-1}), transpiration - E (mmol H_2O m^{-2} s^{-1}), intercellular CO_2 concentration - Ci (μmol CO_2 m^{-2} s^{-1}) and CO_2 assimilation rate - A (μmol CO_2 m^{-2} s^{-1}), evaluated in the third leaf counted from the apex of the fruit-bearing branches, using the portable photosynthesis meter “LCPro+” from ADC BioScientific Ltda. These data were then used to

Table 1. Chemical and physical attributes of the soil used in the experiment

Chemical attributes								
pH (H_2O) (1:2.5)	OM (dag kg^{-1})	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
			($cmol_c$ kg^{-1})					
6.01	2.10	5.30	0.12	0.05	3.0	2.44	0.00	0.69

Chemical attributes				Physical attributes				
EC_{se} (dS m^{-1})	CEC ($cmol_c$ kg^{-1})	SAR_{se} (mmol L^{-1})$^{0.5}$	ESP (%)	Particle-size fraction (g kg^{-1})			Moisture (dag kg^{-1})	
				Sand	Silt	Clay	33.42 kPa[1]	1519.5 kPa[2]
0.71	6.30	0.61	0.79	756.50	200.10	43.40	13.57	5.01

pH - Hydrogen potential, OM - Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} - Extracted with 1 M KCl at pH 7.0; Na^+ and K^+ - Extracted with 1 M NH_4OAc at pH 7.0; Al^{3+}+ H^+ - Extracted with 0.5 M CaOAc at pH 7.0; ECse - Electrical conductivity of saturation extract; CEC - Cation exchange capacity; SAR_{se} - Sodium adsorption ratio of saturation extract; ESP - Exchangeable sodium percentage; [1,2] corresponds to field capacity and permanent wilting point, respectively determine the intrinsic water use efficiency - WUEi (A/E) [(μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$] and instantaneous carboxylation efficiency - CEi [(μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 m^{-2} s^{-1})$^{-1}$]. Readings were performed between 6:30 and 9:00 a.m. on the third fully expanded leaf counted from the apical bud, under natural conditions of air temperature and CO_2 concentration and using an artificial radiation source of 1,200 μmol m^{-2} s^{-1}, established by the photosynthesis-light response curve and the photosynthetic light saturation point (Fernandes et al., 2021).

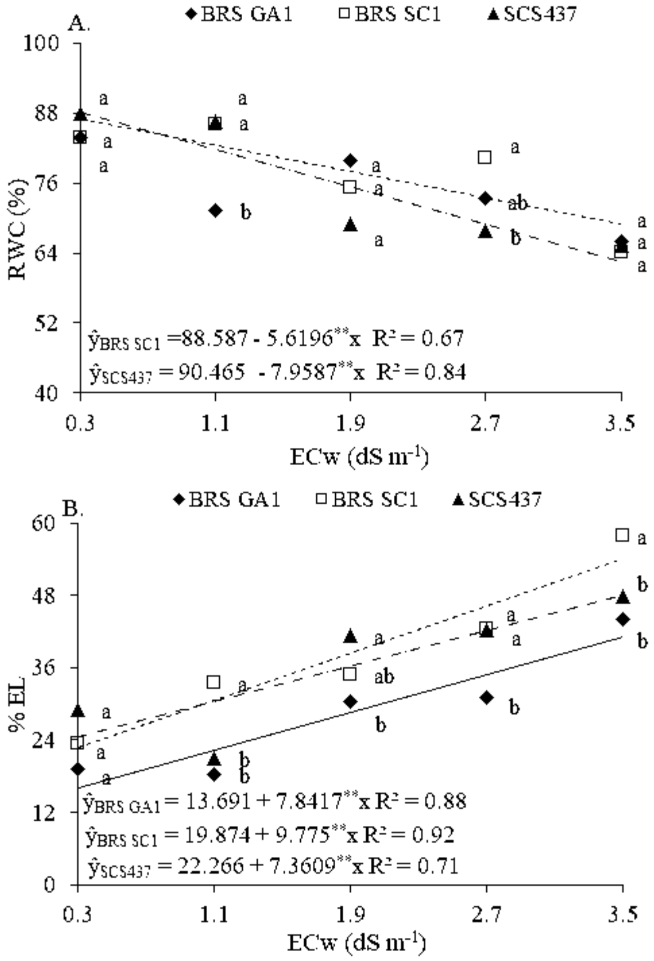
The relative water content was measured according to Weatherley (1950), while electrolyte leakage in the leaf blade was obtained according to the methodology of Scotti-Campos et al. (2013). Harvesting of the fruits began at 97 DAT and ended at 163 DAT and was carried out when the fruits showed a yellow or reddish skin color, as recommended by Costa et al. (2008). After harvest, the following variables were determined: total number of fruits (NF), obtained by counting the fruits; production per plant (PROD), obtained by summing the weight of all fruits harvested; and average fruit weight (AFW), obtained by the relationship between PROD and NF. The tolerance of sour passion fruit to salt stress was determined based on relative production per plant, using the plateau followed by linear decrease model of Maas & Hoffman (1977). The model parameters were fitted by minimizing the square of errors with the Microsoft Excel Solver tool, according to Bione et al. (2021).

The data were subjected to the distribution normality test (Shapiro-Wilk test) at $p \leq 0.05$ and, subsequently, analysis of variance was performed followed by linear and quadratic regression analysis performed for electrical conductivity of the water and means comparison by Tukey test for the cultivars, using the statistical program SISVAR-ESAL (Ferreira, 2019).

Results and Discussion

There was significant effect of the interaction between the factors (SL × CUL) on the relative water content, electrolyte leakage, and intercellular CO_2 concentration of sour passion fruit, at 153 days after transplanting (Table 2). Salinity levels significantly influenced transpiration, stomatal conductance, and CO_2 assimilation rate of sour passion fruit. There was significant effect of cultivars only for intercellular CO_2 concentration. Lima et al. (2021a) evaluated gas exchange in passion fruit (BRS Sol do Cerrado and Guinezinho) under irrigation with water of different salt levels (ECw from 0.3 to 3.5 dS m^{-1}) also found that there was no significant effect of interaction between factors (SL × CUL) for gas exchange variables, at 75 days after sowing.

The relative water content in the leaf blade of sour passion fruit decreased linearly with increasing water salinity (Figure 2A), with reductions of 6.34 and 8.79% per unit increment in ECw for the cultivars BRS SC1 and SCS437, respectively. When comparing the RWC of plants subjected to ECw of 3.5 dS m^{-1} to that of those irrigated with water of 0.3 dS m^{-1}, reductions



** - Significant at $p \leq 0.01$ by the F test; Mean values followed by different letters, at the same ECw value, indicate significant difference between cultivars by Tukey test ($p \leq 0.05$)

Figure 2. Relative water content - RWC (A) and electrolyte leakage - % EL (B) in the leaf blade of sour passion fruit, as a function of the electrical conductivity of water - ECw in each cultivar, at 153 days after sowing

Table 2. Summary of the analysis of variance for relative water content (RWC), electrolyte leakage (% EL), stomatal conductance (gs), transpiration (E), intercellular CO_2 concentration (Ci), and CO_2 assimilation rate (A) of sour passion fruit cultivars (CUL) grown under irrigation with waters of different salinity levels (SL), at 153 days after transplanting (DAT)

Sources of variation	DF	Mean squares					
		RWC	% EL	gs	E	Ci	A
Salinity levels (SL)	4	529.43**	536.51**	0.05**	2.01*	15949.47**	523.21**
Linear regression	1	2025.40**	2038.23**	0.11**	5.72**	25435.21**	1817.73**
Quadratic regression	1	9.01ns	2.64ns	0.065*	0.36ns	27.842.29**	247.94*
Cultivars (CUL)	2	39.92ns	401.67**	0.006ns	1.45ns	2940.06*	20.79ns
Interaction (SL × CUL)	8	101.85**	328.08**	0.01ns	0.71ns	6177.26**	59.12ns
Blocks	2	16.08ns	6.26ns	0.04*	0.098ns	2813.26*	71.31ns
Residual	28	21.29	24.84	0.012	0.54	651.00	52.85
CV (%)		6.12	14.48	6.87	11.61	10.53	15.94

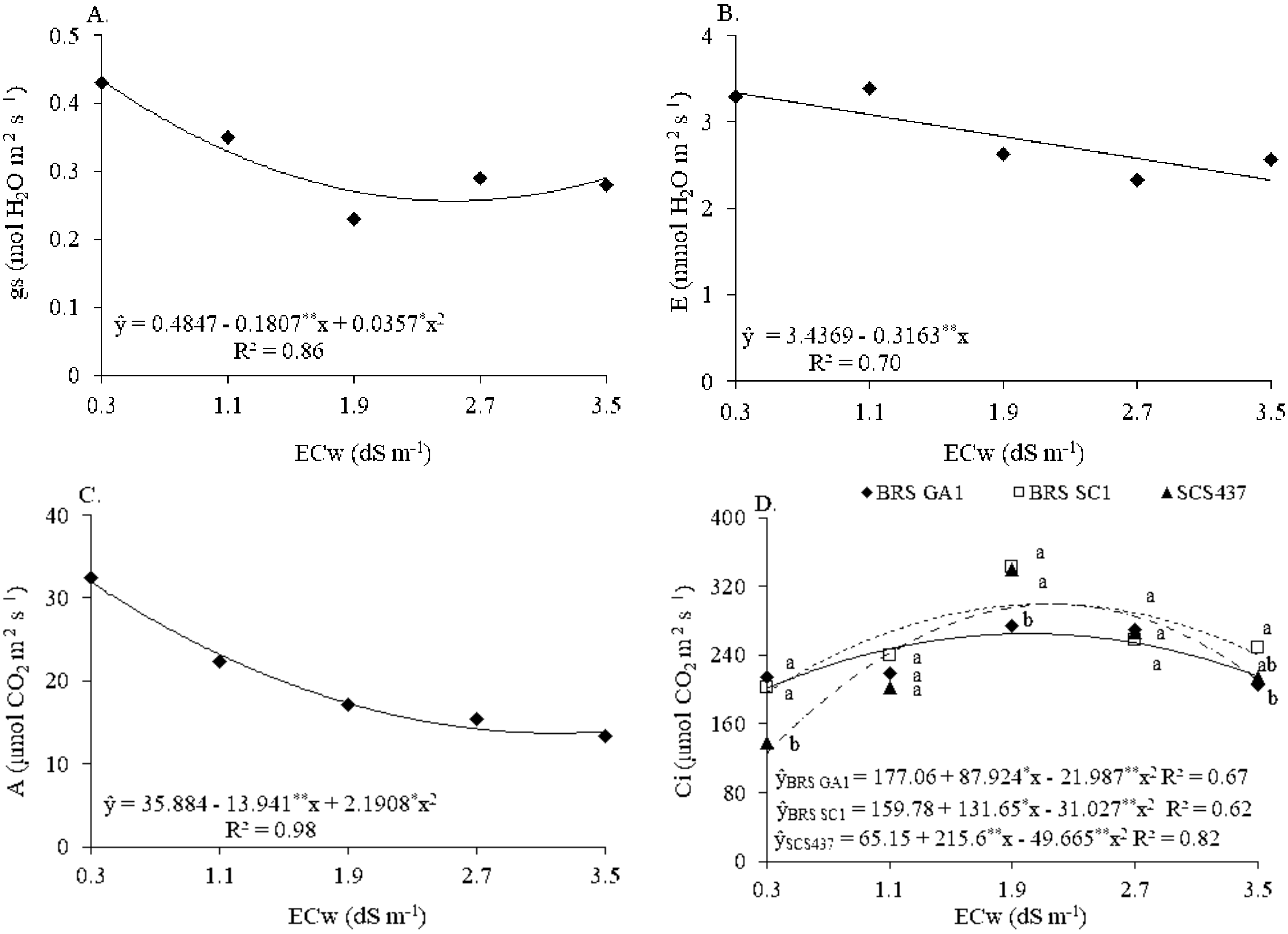
DF - Degrees of freedom; CV (%) - Coefficient of variation; (*) - Significant at $p \leq 0.05$; (**) - Significant at $p \leq 0.01$; (ns) - Not significant by F test of 20.69 and 28.91% were observed for the cultivars BRS SC1 and SCS437, respectively. For the BRS GA1 cultivar, the RWC data (Figure 2A) was not satisfactorily described for prognostic purposes (R^2<0,60) by the tested models ($y = 82.882 - 4.2113^{**}x$ $R^2 = 0.56$). The presence of salts in the root zone triggers osmotic stress, which causes restrictions on the absorption of water and nutrients by plants (Diniz et al., 2020). According to Shahid et al. (2020), high concentrations of salts make it difficult for plants to absorb water from the soil, reducing water conductivity of the root and consequently the relative water content at the cellular level.

In the analysis of cultivars at each value of electrical conductivity of water (Figure 2A), significant differences were observed in the RWC for the cultivars BRS GA1 and BRS SC1 and SCS437 under irrigation with water of 1.1 dS m^{-1}. In plants irrigated with ECw of 2.7 dS m^{-1}, the RWC of BRS SC1 was higher than that of SCS437. There were no significant differences in the RWC of the different cultivars when using water with electrical conductivity of 0.3, 1.9 and 3.5 dS m^{-1}. Reduction in RWC in the leaf blade of sour passion fruit was also observed by Lima et al. (2023) when the plants were subjected to irrigation with water of 4.0 dS m^{-1} in the vegetative, flowering, vegetative/flowering, and vegetative/fruiting stages, compared with plants irrigated with electrical conductivity of 1.3 dS m^{-1} during the entire cycle and in the fruiting stage.

Contrary to the RWC results (Figure 2A), electrolyte leakage in the leaf blade of sour passion fruit plants increased linearly (Figure 2B), by 57.27, 49.18, and 33.05% per unit increment in ECw for the cultivars BRS GA1, BRS SC1, and SCS437, respectively. The increase of electrolyte leakage in the leaf blade may be related to osmotic stress, which causes the overproduction of reactive oxygen species (ROS), which in turn result in damage to the cell membrane. In addition, the movement of salts to plant cells leads to the alternation of plasma membrane permeability (Nguyen et al., 2021) and induces greater electrolyte leakage in the leaf blade of plants.

When analyzing the interaction between the factors (Figure 2B), the % EL of the genotype BRS SC1 was higher than that of the others (BRS GA1 and SCS437) under irrigation with ECw of 1.1 and 3.5 dS m^{-1}. When using water of 1.9 dS m^{-1}, significant differences were observed only between the cultivars BRS GA1 and SCS437. Under ECw of 0.3 dS m^{-1}, there were no significant differences in the % EL between the evaluated cultivars.

The stomatal conductance of sour passion fruit plants decreased with increase in the water salinity, and the maximum value (0.43 mol H_2O m^{-2} s^{-1}) was obtained under water salinity of 0.3 dS m^{-1} (Figure 3A). When comparing gs in relative terms,



*, ** - Significant at p ≤ 0.05 and p ≤ 0.01 by the F test, respectively; Mean values followed by different letters, at the same ECw value, indicate significant difference between cultivars by Tukey test (p ≤ 0.05)

Figure 3. Stomatal conductance - gs (A), transpiration - E (B), and CO_2 assimilation rate - A (C) of sour passion fruit cultivars, as a function of electrical conductivity of water - ECw, and intercellular CO_2 concentration - Ci (D) as a function of the electrical conductivity of water - ECw in each cultivar, at 153 days after sowing

there was a reduction of 33.23% between plants grown under ECw of 3.5 dS m^{-1} and those subjected to 0.3 dS m^{-1}. Normally under conditions of salt stress, plants control the opening and closing of stomata as a strategy to minimize the flow of water vapor to the atmosphere, also reducing the absorption of water and salts, which leads to a lower accumulation of ions in plant tissue, an important factor for most glycophytes exposed to salt stress (Pinheiro et al., 2022). Lima et al. (2021a), when evaluating the effects of water salinity on gas exchange in sour passion fruit (ECw from 0.3 to 3.5 dS m^{-1}), also found that the increase in ECw levels quadratically reduced stomatal conductance, with a decrease of 0.089 mol H_2O m^{-2} s^{-1} between plants grown under ECw of 3.5 and 0.3 dS m^{-1}, at 75 days after sowing.

Leaf transpiration of sour passion fruit was significantly reduced by the electrical conductivity of irrigation water, with decreases of 9.20% per unit increment in ECw (Figure 3B). Plants subjected to ECw of 3.5 dS m^{-1} reduced their E by 30.328% (1.01 mmol H_2O m^{-2} s^{-1}) compared to those cultivated under water salinity of 0.3 dS m^{-1}. Reduction in plant transpiration reflects the partial closure of the stomata and occurs due to the osmotic effects, which inhibit the absorption of water by plants, limiting the flow of water vapor into the atmosphere (Dias et al., 2019). Diniz et al. (2020), in a study with yellow passion fruit seedlings under irrigation water salinity (between ECw 0.3 and 3.1 dS m^{-1}), found a linear reduction in leaf transpiration, with decreases of 13.35% per unit increment in ECw. In the present study, plants subjected to ECw of 3.5 dS m^{-1} obtained an average value of 2.32 mmol H_2O m^{-2} s^{-1}, being 0.610 mmol H_2O m^{-2} s^{-1} higher than that observed in plants grown under water salinity of 3.1 dS m^{-1} from the study conducted by Diniz et al. (2020).

The CO_2 assimilation rate of sour passion fruit plants decreased quadratically with increasing value of electrical conductivity of water (Figure 3C), and the maximum value of 31.89 μmol CO_2 m^{-2} s^{-1} was obtained in plants grown under ECw of 0.3 dS m^{-1}. Irrigation with water of 3.2 dS m^{-1} resulted in the minimum estimated value of 13.70 μmol CO_2 m^{-2} s^{-1}. When comparing the assimilation rate of plants irrigated with water of 3.5 dS m^{-1} to that of plants that received water of 0.3 dS m^{-1}, a decrease of 56.33% was observed. The reduction in the photosynthesis rate of sour passion fruit plants under salt stress conditions is related to the action of stomatal and non-stomatal factors, such as the restriction of CO_2 diffusion in the mesophyll cells and a decrease in the affinity of ribulose-1,5-biphosphate carboxylase-oxygenase (RuBisCO) with CO_2 (Soares et al., 2023), including changes in chlorophyll and carotenoid concentrations (Dias et al., 2019; Diniz et al., 2020). Silva et al. (2019), when evaluating the gas exchange of passion fruit as a function of irrigation with saline waters (ECw ranging from 0.7 to 2.8 dS m^{-1}), observed that the lowest CO_2 assimilation rate (8.18 μmol CO_2 m^{-2} s^{-1}) was obtained in plants irrigated with water of 2.8 dS m^{-1}.

The intercellular CO_2 concentration of the sour passion fruit cultivars BRS GA1, BRS SC1, and SCS437 reached the estimated maximum values of 264.96, 299.41, and 299.09 μmol CO_2 m^{-2} s^{-1}, respectively, when they were irrigated with ECw of 2.0, 2.1, and 2.2 dS m^{-1} (Figure 3D); these ECw values caused a reduction in Ci, and values of 215.45, 240.47, and 211.35 μmol CO_2 m^{-2} s^{-1} were obtained in the cultivars BRS GA1, BRS SC1, and SCS437 under water salinity of 3.5 dS m^{-1}. The increase in the internal CO_2 concentration in plants grown under salt stress is indicative that the CO_2 absorbed in the substomatal chamber was not assimilated during the photosynthetic process, possibly due to the low activity of the enzyme Ribulose-1,5-biphosphate carboxylase/oxygenase (Lima et al., 2023). In the analysis of cultivars considering each water salinity level (Figure 3D), there was a significant effect only when plants were irrigated with ECw of 0.3, 1.9, and 3.5 dS m^{-1}. The cultivars BRS GA1 and BRS SC1 were superior to SCS437 under water salinity of 0.3 dS m^{-1}. On the other hand, under ECw of 1.9 and 3.5 dS m^{-1}, the lowest Ci was observed in the genotype BRS GA1.

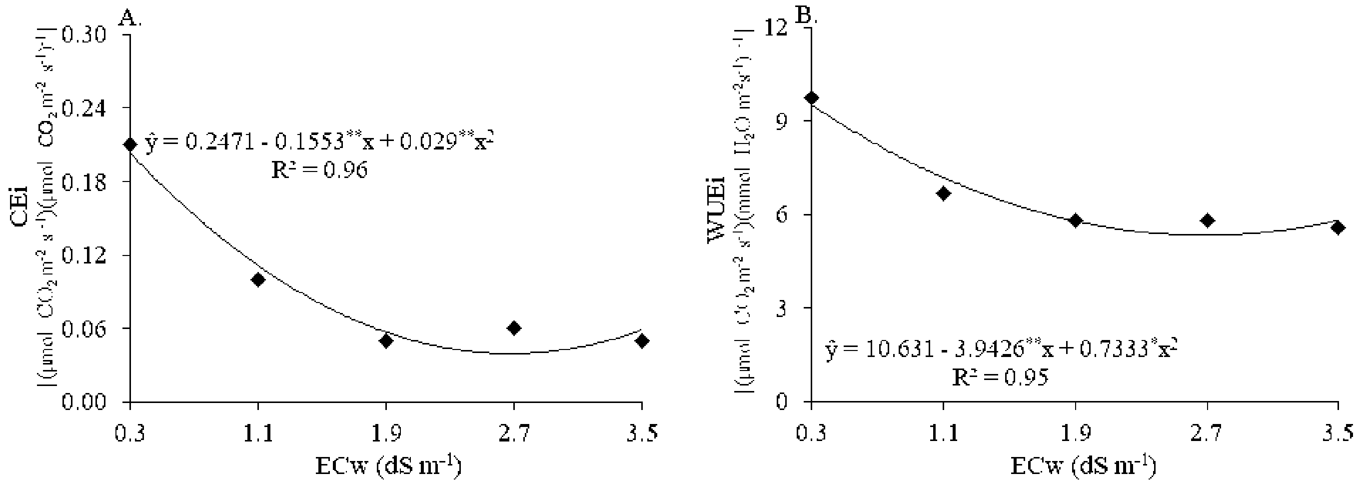
There was a significant effect of the interaction between the factors (SL × CUL) on the production per plant of sour passion fruit (Table 3). The water salinity levels significantly influenced the instantaneous carboxylation efficiency and intrinsic water use efficiency, number of fruits and production per plant. The cultivars of sour passion fruit significantly affected only the production per plant of sour passion fruit. The average fruit weight was not significantly affected by the sources of variation tested.

The instantaneous carboxylation efficiency was also negatively affected by water salinity (Figure 4A), and its maximum estimated value of 0.203 [(μmol CO_2 m^{-2} s^{-1}) (μmol m^{-2} s^{-1})$^{-1}$] was observed in plants irrigated with ECw of 0.3 dS m^{-1}. When comparing the CEi of plants subjected to the highest

Table 3. Summary of the analysis of variance for instantaneous carboxylation efficiency (CEi), intrinsic water use efficiency (WUEi), at 153 days after transplanting (DAT), number of fruits (NF), production per plant (PROD), and average fruit weight (AFW) of sour passion fruit cultivars cultivated under irrigation with waters of different electrical conductivity values (SL)

Sources of variation	DF	Mean Squares				
		CEi	WUEi	NF	PROD	AFW
Salinity levels (SL)	4	0.04**	27.47**	60.1444**	9455.01**	122.32ns
Linear regression	1	0.11**	76.692071**	190.6777**	32777.15**	59.38ns
Quadratic regression	1	0.04**	27.814603*	3.5000ns	3256.07**	0.67ns
Cultivars (CUL)	2	0.002ns	1.044882ns	19.8222ns	5539.84**	135.09ns
Interaction (SL × CUL)	8	0.007ns	5.768213ns	14.7111ns	2493.40**	169.78ns
Blocks	2	0.008ns	13.093796ns	35.6222ns	137.97ns	146.40ns
Residual	28	0.003	5.434843	11.360317	125.37	94.24
CV (%)		4.60	15.08	23.59	6.67	22.74

DF - Degrees of freedom; CV (%) - Coefficient of variation; (*) - Significant at p ≤ 0.05; (**) - Significant at p ≤ 0.01; (ns) - Not significant by F test



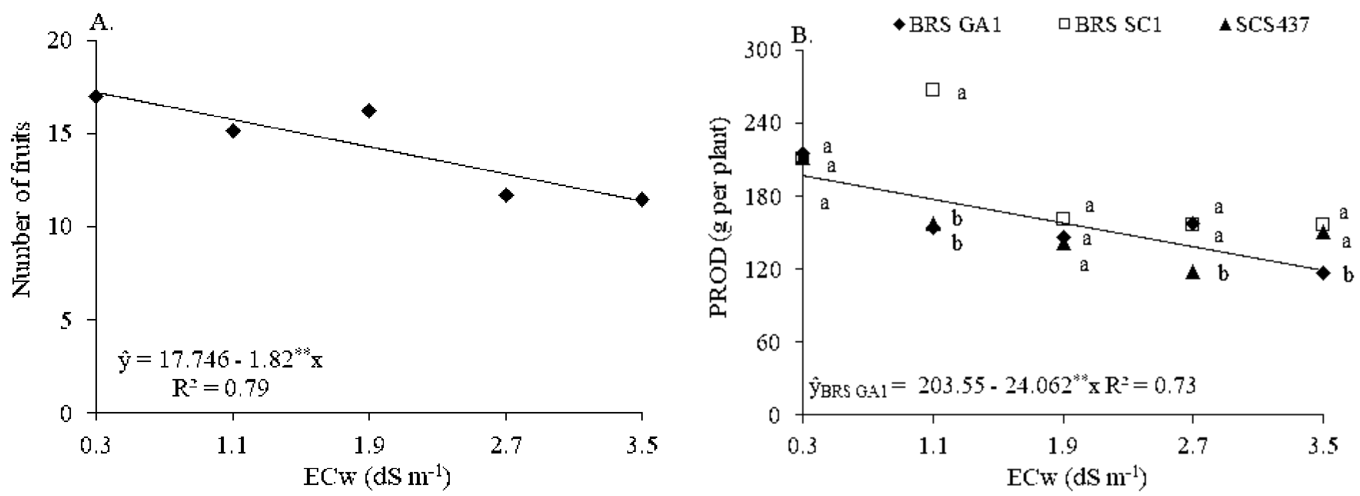
*, ** - Significant at p ≤ 0.05 and p ≤ 0.01 by the F test, respectively

Figure 4. Instantaneous carboxylation efficiency - CEi (A) and intrinsic water use efficiency - WUEi (B) of sour passion fruit cultivars, as a function of irrigation water electrical conductivity- ECw, at 153 days after transplanting

level of electrical conductivity of water (3.5 dS m^{-1}) to that of plants irrigated with ECw of 0.3 dS m^{-1}, a reduction of 0.144 [(μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 m^{-2} s^{-1})$^{-1}$] was observed. The decrease in the instantaneous carboxylation efficiency of sour passion fruit plants under salt stress indicates the action of factors of non-stomatal origin possibly related to the inhibition of the activity of RuBisCO, caused by the accumulation of toxic ions, mainly Na^+ and Cl^-. Excess salts may induce RuBisCO oxygenation and increase the photorespiratory pathway (Lima et al., 2019).

As observed for CEi (Figure 4A), the intrinsic water use efficiency of sour passion fruit plants (Figure 4B) decreased significantly with the increase in the electrical conductivity of the water. The maximum estimated value, 9.51 [(μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{1}) $^{-1}$], was reached in plants grown under ECw of 0.3 dS m^{-1}, decreasing from this water salinity level. When comparing the WUEi of plants irrigated with water of 3.5 dS m^{-1} to that of plants cultivated under ECw of 0.3 dS m^{-1}, a decrease of 3.699 [(μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$] was observed. It is important to highlight that the absorption of CO_2 from the external environment by the stomata also causes water loss, and to reduce this loss the plant restricts the entry of CO_2, which directly interferes with WUEi.

The number of fruits of sour passion fruit was negatively affected by the salinity of irrigation water, with a decrease of 10.25% per unit increment in ECw (Figure 5A). When comparing in relative terms the NF of plants grown under ECw of 3.5 dS m^{-1} to that of plants subjected to the lowest water salinity level (0.3 dS m^{-1}), a reduction of 33.86% (5.82 fruits per plant) was observed. The reduction in the number of fruits of sour passion fruit plants may be related to the diversion of energy for maintaining metabolic activities, consequently causing a reduction in plant growth and production (Pinheiro et al., 2022). This situation reflects the action of osmotic effects, interfering with the absorption of water and nutrients by plants (Diniz et al., 2020). Reduction in the production of sour passion fruit due to salt stress was also observed by Nunes et al. (2023), who found that the increase in ECw from 0.35 to 4.0 dS m^{-1} resulted in an 11.80% (13.25 fruits) decrease in the number of fruits per plant.



** - Significant at p ≤ 0.01 by the F test; Mean values followed by different letters, for the same ECw value, indicate significant difference between cultivars by Tukey test (p ≤ 0.05)

Figure 5. Number of fruits per plant of sour passion fruit cultivars grown under electrical conductivity of water - ECw (A) and production per plant - PROD, as a function of the electrical conductivity of water - ECw in each cultivar (B)

The production per plant decreased linearly with the increase in electrical conductivity of water (Figure 5B), by 11.82% per unit increment in ECw for the cultivar BRS GA1. When comparing the production of plants subjected to ECw of 3.5 dS m^{-1} to that of plants that received the lowest salinity level (0.3 dS m^{-1}), a decrease between 34.2 and 39.21% was observed for the cultivars. The PROD data of the cultivars BRS SC1 ($y_{BRS\ SC1}$ = 242.03 - 27.349**x, R^2 = 0.50) and SCS 437 (y_{SCS437} = 194.11 - 20.153**x, R^2 = 0.54) did not obtain satisfactory fits for prognostic purposes by the tested models. The decrease in production per plant results from the limitations that occurred in the gas exchange of sour passion fruit, which directly interferes with the absorption of water and nutrients, in addition to reducing the allocation of photoassimilates. The use of energy to restrict the absorption of Na^+ and the biosynthesis of osmolytes to reduce osmotic potential under salt stress can lead to a reduction in growth and consequently in production (Behdad et al., 2021; Souto et al., 2023). Ramos et al. (2022), when evaluating the production of sour passion fruit under irrigation with saline water (ECw: 0.6 to 3.0 dS m^{-1}), also observed that the increase in ECw reduced PROD by 13.72% per unit increment in ECw.

In the analysis of cultivars considering each value of electrical conductivity of water (Figure 5B), there were significant differences when plants were subjected to ECw of 1.1, 2.7, and 3.5 dS m^{-1}. Under ECw of 1.1 dS m^{-1}, the cultivar BRS SC1 was superior to BRS GA1 and SCS437 in production. Irrigation with water of 2.7 dS m^{-1} resulted in the highest production for the cultivars BRS GA1 and BRS SC1. Under ECw of 3.5 dS m^{-1}, the highest production was observed in the cultivars BRS SC1 and SCS437. The variation in the degree of tolerance of sour passion fruit cultivars to salt stress may be associated with the genetic characteristics of each cultivar and may vary according to the development stage, the level and nature of the cationic and/or anionic medium, stress intensity and duration, edaphoclimatic conditions, and irrigation management.

The irrigation water salinity threshold obtained in this study by the plateau followed by linear decrease model (Maas & Hoffman, 1977) for the cultivars BRS GA1, BRS SC1, and SCS437 was 0.3, 1.0, and 0.3 dS m^{-1}, respectively (Figures 6A, B, and C), and the reductions per unit increment above threshold ECw were 14.80, 12.33, and 14.96%, respectively. However, irrigation with ECw of 2.33, 3.41, and 2.31 dS m^{-1} for BRS GA1, BRS SC1, and SCS437, respectively, can result in relative production of up to 70% of their production per plant.

In turn, irrigation with water of 3.67, 5.06, and 3.64 dS m^{-1} makes it possible to obtain a relative production of 50%. Considering the degree of tolerance established by Maas & Hoffman (1977), based on relative production and decreases per unit increase above the respective threshold levels, the studied sour passion fruit cultivars (BRS GA1, BRS SC1, and SCS437) are classified as sensitive. Lima et al. (2021a) found in a study with passion fruit under irrigation with saline water (ECw from 0.3 to 3.5 dS m^{-1}) that the BRS Sol do Cerrado cultivar and the Guinezinho accession are sensitive to water salinity from 0. 3 dS m^{-1}.

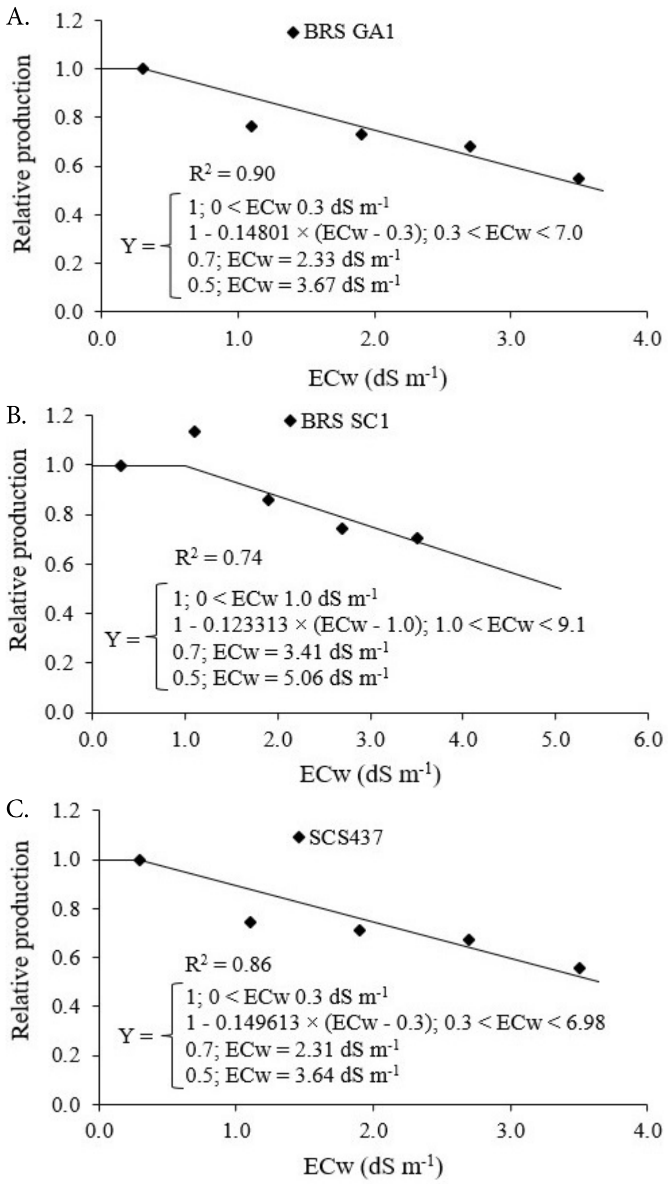


Figure 6. Relative production of sour passion fruit cultivars: BRS GA1 (A), BRS SC1 (B), and SCS437 (C), as a function of the electrical conductivity of irrigation water - ECw described by the plateau model of Maas & Hoffman (1977)

Conclusions

1. Electrical conductivity of water from 0.3 dS m^{-1} reduces relative water content, gas exchange, number of fruits, and production per plant and increases electrolyte leakage in the leaf blade, regardless of sour passion fruit cultivars, at 153 days after transplanting.

2. The sour passion fruit cultivars BRS GA1, BRS SC1, and SCS437 are classified as sensitive to water salinity, with electrical conductivity threshold values of 0.3, 1.0 and 0.3 dS m^{-1}.

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