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SOIL SCIENCE

Potassium fertilization as salt stress attenuator in sour passion fruit

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ABSTRACT: Water scarcity associated with irregular rainfall in the semi-arid region of Northeastern Brazil stands out as a limiting factor for agricultural production. Thus, the use of waters with high concentration of salts is an alternative to expand irrigated agriculture in this region. In this context, this study evaluated the water status, intercellular electrolyte leakage, photosynthetic pigments, and gas exchange of 'BRS SC1' sour passion fruit as a function of irrigation with water of different levels of salinity and potassium doses. The experiment was carried out in pots adapted as drainage lysimeters under field conditions at the Experimental Farm of the Federal University of Campina Grande in São Domingos – PB, Brazil. The experimental design was randomized blocks, in a 5 × 4 factorial scheme, whose treatments were obtained by combining two factors: five levels of electrical conductivity of irrigation water - ECw (0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}), associated with four potassium doses (60, 80, 100, and 120% of the recommendation), with three replicates. Water with electrical conductivity greater than 0.3 dS m^{-1} reduced the relative water content, chlorophyll *a* and chlorophyll *b* contents, CO_2 assimilation rate, and instantaneous water use efficiency of 'BRS SC1' sour passion fruit plants. The estimated potassium dose of 85% of the recommendation (equivalent to 293 g per plant per year) mitigated the deleterious effects of salt stress on stomatal conductance, transpiration, internal CO_2 concentration, and instantaneous carboxylation efficiency of passion fruit 'BRS SC1'.
Key words: salt stress, attenuation, semi-arid region, *Passiflora edulis* Sims.

Adubação potássica como atenuante do estresse salino em maracujazeiro-azedo

RESUMO: A escassez de água associada à irregularidade das precipitações no semiárido do Nordeste brasileiro destaca-se como fator limitante para produção agrícola. Assim, o uso de águas com elevadas concentrações de sais é uma alternativa para expandir a agricultura irrigada nesta região. Neste contexto, objetivou-se com este trabalho avaliar os status hídrico, o extravasamento de eletrólitos, os pigmentos fotossintéticos e as trocas gasosas do maracujazeiro-azedo 'BRS SC1' em função da irrigação com águas de diferentes salinidades e doses de potássio. O experimento foi desenvolvido em vasos adaptados como lisímetros de drenagem sob condições de campo na Fazenda Experimental da Universidade Federal de Campina Grande em São Domingos – PB. O delineamento experimental foi o de blocos casualizados, em esquema fatorial 5 × 4, cujos tratamentos foram construídos pela combinação de dois fatores: cinco níveis de condutividade elétrica da água de irrigação – CEa (0,3; 1,1; 1,9; 2,7 e 3,5 dS m^{-1}), associados a quatro doses de potássio (60; 80; 100 e 120% da recomendação), com três repetições. A água de condutividade elétrica superior a 0,3 dS m^{-1} reduziu o conteúdo relativo de água, os teores de clorofila *a* e *b*, a taxa de assimilação de CO_2 e a eficiência instantânea no uso da água das plantas de maracujazeiro-azedo 'BRS SC1'. A dose de potássio estimada de 85% da recomendação (equivalente a 293 g por planta ano), amenizou os efeitos deletérios do estresse salino sobre a condutância estomática, transpiração, concentração interna de CO_2 e eficiência instantânea de carboxilação do maracujazeiro-azedo 'BRS SC1'.
Palavras-chave: estresse salino, atenuação, semiárido, *Passiflora edulis* Sims.

INTRODUCTION

Passion fruit (*Passiflora edulis* Sims) is a fruit crop belonging to the Passifloraceae family. According to ARAÚJO et al. (2012), this crop has stood out in the fruit market, because it is highly profitable to family farming and ensures a source of income well distributed throughout the year, especially in the Northeast region, which has favorable edaphoclimatic conditions for its cultivation.

Brazil is the largest producer of this fruit crop, reaching, in 2021, a production of 683,993 tons in an area of 44,827 hectares. Among the regions of the country, the Northeast stands out as the largest producer

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of this fruit, accounting for about 69.6% of the total produced nationally (476,006 tons). However, when it comes to yield, this region has an average yield of only 12,540 kg ha^{-1}, which is well below the 19,130 kg ha^{-1} observed in the southern region of the country (IBGE, 2021) which demonstrates that there is still much of the production capacity of the crop to be exploited.

This low production efficiency may be related to several factors, including the lack of adequate management, ineffective fertilization, and mainly the use of waters with salt contents above that tolerated by plants (FREIRE et al., 2020; PINHEIRO et al., 2022), since in this region fruit crops are limited to the use of irrigation, due to the spatial-temporal variability of rainfall, combined with the high evaporative demand, making it necessary to use water resources of restrictive quality for crop production (FREIRE et al., 2016; SILVA et al., 2018). In the semi-arid region of Northeast Brazil, the electrical conductivity of the water of springs used for irrigation varies between 0.3 and 3.0 dS m^{-1} depending on the time of year and the geology of the place.

In general, the salinity of irrigation water inhibits plant growth through osmotic and ionic effects that restrict the absorption of water and essential elements (SOUZA et al., 2016; TANAKA et al., 2018), leading to changes in the ion balance of plant tissues as well as disturbances in plant metabolism (ZHANG et al., 2019). In addition, it induces excessive production of reactive oxygen species, as by-products of cellular metabolism, which damage important cellular components, degrade chlorophyll, and cause lipid peroxidation of the membrane, thus reducing membrane fluidity and selectivity (TAÏBI et al., 2016).

Thus, the viability of these water resources with high concentrations of dissolved salts as an alternative to the water limitations inherent to the arid and semi-arid regions of Northeastern Brazil are conditioned on the use of strategies that ensure the sustainability of crops, especially in the long term. ABBASI et al. (2016) state that potassium fertilization should be considered as an alternative capable of mitigating salt stress in plants, enabling the use of these resources in agriculture. Corroborating this premise, in the literature (PRAZERES et al., 2015; LIMA et al., 2018; DIAS et al., 2019; OLIVEIRA et al., 2021), studies have demonstrated the potential of increased potassium supply to crops as an attenuator of the deleterious effects of salinity of water used in irrigation.

Potassium plays na important role in physiological processes, when applied in a balanced way, it promotes improvement in osmotic regulation and the maintenance of ionic homeostasis under saline stress conditions (LIMA et al., 2018). In addition, it reduces the absorption of Na^+ and Cl^- by plants, due to the competition between these nutrients for the absorption site (MENEGHETTE et al., 2017), which may reflect on the reduction of the deleterious effects of irrigation water salinity.

This study is based on the hypothesis that the adequate management of potassium doses induces tolerance to salt stress in the sour passion fruit, through osmotic regulation and maintenance of ionic homeostasis. In this context, the objective of this study was to evaluate the water status, electrolyte leakage, photosynthetic pigments, and gas exchange of 'BRS SC1' sour passion fruit as a function of irrigation with waters of different salinity levels and potassium doses.

MATERIALS AND METHODS

The experiment was conducted from June to August 2021, in 60-L pots adopted as drainage lysimeters under field conditions in the experimental area belonging to the 'Rolando Enrique Rivas Castellón' farm, at the Center of Sciences and Agri-Food Technology - CCTA of the Federal University of Campina Grande - UFCG, located in the municipality of São Domingos, Paraíba, Brazil. The data of temperature (maximum and minimum) and mean relative air humidity of the experimental site are shown in figure 1.

A randomized block design was used in a 5 × 4 factorial scheme, whose treatments were obtained by combining two factors: five levels of the electrical conductivity of irrigation water - ECw (0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}), associated with four potassium doses (60, 80, 100, and 120% of the recommendation), with three replicates. The dose of 100% corresponded to application of 345 g of K_2O per plant per year (COSTA et al., 2008).

Sour passion fruit cv. 'BRS Sol do Cerrado' ('BRS SC1') seeds were used in the study. 'BRS SC1' sour passion fruit is characterized by having fruits with oblong shape, tapered at the apex and more rounded at the base. Its fruits weigh between 150 to 350 g and have pulp yield around 38% and soluble solids content from 13 to 14° Brix (EMBRAPA, 2008).

The research was carried out in two stages: in the first stage, 2 seeds were sown in plastic bags 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 emergence of the seedlings, thinning was performed, leaving only

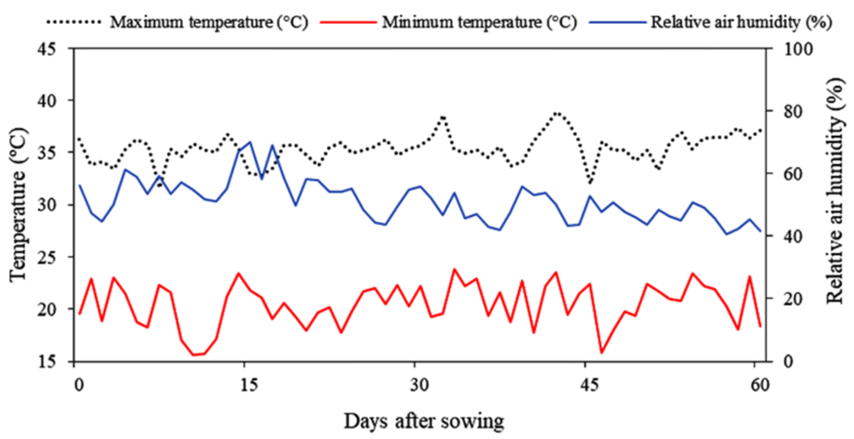

Figure 1 - Maximum and minimum daily temperature and mean relative air humidity observed in the internal area of the greenhouse during the experimental period.

one plant per container, when they were 10 cm tall. When tendrils began to grow, the seedlings were transplanted to lysimeters, starting the second stage.

The lysimeters were filled with a 0.5-kg layer of crushed stone, placed on a non woven geotextile (Bidim), followed by a 80-kg layer of soil from the experimental area of CCTA/UFCG. The soil of the experimental area was classified as *Neossolo Flúvico Ta Eutrófico típico* (Entisol) of sandy loam texture. The chemical and physical characteristics (Table 1) were obtained according to the methodology proposed by TEIXEIRA et al. (2017).

The seedlings were kept with the collar region - a region of transition between the root system and the trunk - at ground level, avoiding their deepening. Phosphorus was applied in a single dose, incorporated with the soil when the lysimeters were filled, while nitrogen fertilization was applied as top-dressing monthly after the establishment of the seedlings, an average amounts of 10 g of N per plant, as recommended by COSTA et al. (2008). Ammonium sulfate, single superphosphate, and potassium chloride were used as a source of NPK. Micronutrients were applied weekly at the concentration of 1 g L^{-1}, by foliar spraying, using a compound of Dripsol micro® (Mg^{2+} = 1.1%; Boron = 0.85%; Copper (Cu-EDTA) = 0.5%; Iron (Fe-EDTA) = 3.4%; Manganese (Mn-EDTA) = 3.2%; Molybdenum = 0.05%; Zinc = 4.2%; 70% EDTA chelating agent).

After transplanting to the lysimeters, bamboo stakes were used to support the seedlings to make them grow straight up to the trellis height. Unwanted

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

----------Chemical characteristics----------								
pH_{H2O}	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
(1:2.5)	dag kg^{-1}	(mg kg^{-1})				$cmol_c$ kg^{-1}		
7.82	0.81	10.60	0.30	0.81	2.44	1.81	0	0
----------Chemical characteristics----------				----------Physical characteristics----------				
EC_{se}	CEC	SAR_{se}	ESP	Particle-size fraction (g kg^{-1})			Moisture (dag kg^{-1})	
(dS m^{-1})	$cmol_c$ kg^{-1}	(mmol $L^{-1})^{0.5}$	%	Sand	Silt	Clay	33.42 kPa[1]	1519.5 kPa[2]
1.52	5.36	6.67	15.11	820.90	170.10	9.00	12.87	5.29

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] referring to field capacity and permanent wilting point.

branches were removed until the seedlings reached the trellis height and, from this point on, they were conducted appropriately. The seedlings were conducted with a single stem. At 15 days after transplanting the seedlings, formative pruning began, eliminating all lateral shoots and leaving only the main stem, which was guided by a stake until reaching the support wire.

A spacing of 3 m between rows and 3 m between plants was used, adopting the trellis system. This trellis provided support for passion fruit plants. A string was used to conduct the plants to the trellis. When the plants reached 10 cm above the trellis, their apical bud was pruned to stimulate the growth of secondary branches, which were trained one to each side up to a length of 1.50 m.

After the secondary branches reached this length, the apical bud of these branches was pruned to stimulate the growth of tertiary branches, which were conducted downwards up to 30 cm from the soil, forming a curtain, and produced the inflorescences, which originated the fruits. Throughout the experiment, tendrils and unwanted branches were eliminated to favor the development of the crop. The water used for irrigation in the treatment of the lowest salinity (0.3 dS m^{-1}) came from the public supply system of Pombal – PB, while the other ECw levels were prepared by adding NaCl in public-supply water. The irrigation water was prepared considering the relationship between ECw and salt concentration (RICHARDS, 1954), according to Eq. 1:

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

where:
Q = Quantity of salts to be dissolved (mg L^{-1});
ECw = Desired electrical conductivity of water (dS m^{-1})
Irrigation was performed daily at 17:00 h, applying in each container the volume corresponding to that obtained by the water balance, determined by Eq. 2:

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

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

At 60 days after transplanting (DAT), the relative water content (RWC), intercellular electrolyte leakage (IEL), contents of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and carotenoids (Car), and gas exchange by stomatal conductance (*gs*) (mol H_2O m^{-2} s^{-1}), transpiration (*E*) (mmol H_2O m^{-2} s^{-1}), CO_2 assimilation rate (*A*) (μmol CO_2 m^{-2} s^{-1}), and internal CO_2 concentration (μmol CO_2 m^{-2} s^{-1}) (*Ci*) were 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 determine the instantaneous 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})$^{-1}$.

To determine the relative water content (RWC) in the leaf blade, three fully expanded leaves were collected from the upper third of the plant and immediately weighed to avoid moisture losses and obtain the fresh mass (FM); then, these samples were placed in plastic bags, immersed in distilled water, and stored for 24 hours. After this period and after drying the excess water with paper towels, the turgid mass (TM) of the samples was obtained and they were taken to the oven (temperature ≈ 65 ± 3 ºC), to dry until constant weight to obtain the dry mass (DM) of the samples. RWC was determined according to WEATHERLEY (1950), using Eq. 3:

$$RWC = \frac{(FM-DM)}{(TM-DM)} x100 \qquad (3)$$

where:
RWC = Relative water content (%);
FM= leaf fresh mass (g);
TM= turgid mass (g);
DM = dry mass (g);
Intercellular electrolyte leakage in the leaf blade of sour passion fruit plants was obtained according to SCOTTI-CAMPOS et al. (2013), using Eq. 4:

$$IEL = \frac{Ci}{Cf} x100 \qquad (4)$$

where:
IEL = Intercellular electrolyte leakage in the leaf blade (%);
Ci = initial electrical conductivity (dS m^{-1});
Cf = final electrical conductivity (dS m^{-1}).
Chlorophyll and carotenoid contents were determined using the spectrophotometer at absorbance wavelength (ABS) 470, 647, and 663 nm, according to the methodology of ARNON (1949), using Eqs. 5, 6 and 7:

$$Chl\ a = 12.21\ ABS_{663} - 2.81\ ABS_{647} \qquad (5)$$
$$Chl\ b = 20.13\ ABS_{647} - 5.03\ ABS_{663} \qquad (6)$$
$$Car = (1000\ ABS_{470} - 1.82\ Chl\ a - 85.02\ Chl\ b)/198 \qquad (7)$$

where:
Chl *a* = Chlorophyll *a*;
Chl *b* = Chlorophyll *b*;
Car - Total carotenoid.

The values obtained for chlorophyll *a*, chlorophyll *b,* and carotenoids contents in the leaves were expressed in μg mL^{-1}.

The data were subjected to the distribution normality test (Shapiro-Wilk test) at a 0.05 probability level. Then, analysis of variance was performed at 0.05 probability level and, in cases of significance, linear and quadratic regression analysis was performed, using the statistical program SISVAR-ESAL. The regression model (linear or quadratic) was chosen based on the significance of the coefficients of determination. In case of a significant effect of the interaction between factors, Table Curve 3D software was used to create the response surfaces.

RESULTS

There was a significant effect of salinity levels on the relative water content (RWC) and intercellular electrolyte leakage (IEL) in the leaf blade, and contents of chlorophyll *a*, chlorophyll *b*, and carotenoids (Car) of sour passion fruit plants (Table 2). Potassium doses significantly affected only electrolyte leakage in the leaf blade. Conversely, the interaction between the factors (SL × KD) did not significantly influence any variable analyzed.

The relative water content in the leaf blade of 'BRS SC1' sour passion fruit plants decreased linearly as a function of irrigation water salinity (Figure 2A), by 4.40% per unit increment in ECw. In relative terms, when plants under irrigation with ECw of 3.5 dS m^{-1} were compared to those that received the lowest salinity level (0.3 dS m^{-1}), there was a decrease of 14.29%.

Intercellular electrolyte leakage in the leaf blade of sour passion fruit plants increased quadratically with the increase in water salinity levels (Figure 2B). It was verified that the maximum estimated value (16.55%) was obtained in plants under ECw of 2.8 dS m^{-1}, decreasing from this salinity level. The regression equation (Figure 2B) showed that plants under water salinity of 0.3 dS m^{-1} obtained the lowest IEL (12.30%).

Potassium doses also quadratically influenced electrolyte leakage in the leaf blade of sour passion fruit plants (Figure 2C). It is observed by the regression equation that the maximum estimated value of IEL (16.107%) was reached in plants subjected to fertilization with 100% of the K recommendation; above this dose, there was a decrease in this trait. It is worth mentioning that the lowest IEL value (13.887%) was reported when using the lowest dose of K (60%). When the IEL of plants under the dose of 120% was compared to that of plants that received 60% of the K recommendation, there was an increase of 1.650%.

The chlorophyll *a* content of sour passion fruit plants decreased linearly with increasing water salinity (Figure 3A), by 12.16% per unit increment in ECw. It is observed that plants subjected to ECw of 3.5 dS m^{-1} reduced their Chl *a* content by 40.41% (6.264 μg mL^{-1}) compared to those irrigated with water of the lowest salinity level (0.3 dS m^{-1}).

The chlorophyll *b* content of sour passion fruit plants decreased with increasing water salinity (Figure 3B). According to the regression equation, as the water salinity levels increased, there was a decrease of 12.37% per unit increment in ECw. Plants grown under water salinity of 3.5 dS m^{-1} had their Chl *b* content reduced by 41.13% (1.448 μg mL^{-1}) compared to those irrigated with ECw of 0.3 dS m^{-1}.

The carotenoid contents (Figure 3C) of sour passion fruit plants increased quadratically as a function of the electrical conductivity levels of the irrigation water. Plants subjected to the electrical conductivity level of 2.8 dS m^{-1} obtained

Table 2 - Summary of the analysis of variance for the relative water content (RWC), intercellular electrolyte leakage in the leaf blade (IEL), and contents of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and carotenoids (Car) of 'BRS SC1' sour passion fruit plants cultivated with saline water and potassium doses, at 60 days after transplanting.

Source of variation	DF	--------Mean squares--------				
		RWC	IEL	Chl *a*	Chl *b*	Car
Saline levels (SL)	4	248.95^{**}	39.81^{*}	75.40^{*}	4.21^{*}	3.81^{*}
Linear regression	1	889.98^{**}	115.95^{**}	294.34^{**}	16.59^{**}	11.32^{**}
Quadratic regression	1	90.46^{ns}	30.82^{*}	0.35^{ns}	0.005^{ns}	3.10^{*}
Potassium doses (PD)	3	22.95^{ns}	30.55^{*}	0.90^{ns}	0.56^{ns}	1.42^{ns}
Linear regression	1	25.12^{ns}	51.95^{*}	0.21^{ns}	0.003^{ns}	0.48^{ns}
Quadratic regression	1	42.50^{ns}	41.02^{*}	0.64^{ns}	0.100^{ns}	0.21^{ns}
Interaction (SL × PD)	12	19.73^{ns}	10.48^{ns}	19.25^{*}	1.18^{ns}	1.07^{ns}
Blocks	2	27.18^{ns}	1.28^{ns}	15.32^{ns}	1.42^{ns}	1.69^{ns}
Residual	38	12.75	8.90	10.33	0.87	0.72
CV(%)		5.21	19.72	14.17	18.27	13.44

DF - degrees of freedom; CV (%) - coefficient of variation; *significant at 0.05 probability level; ** significant at 0.01 probability level; ^{ns} not significant.

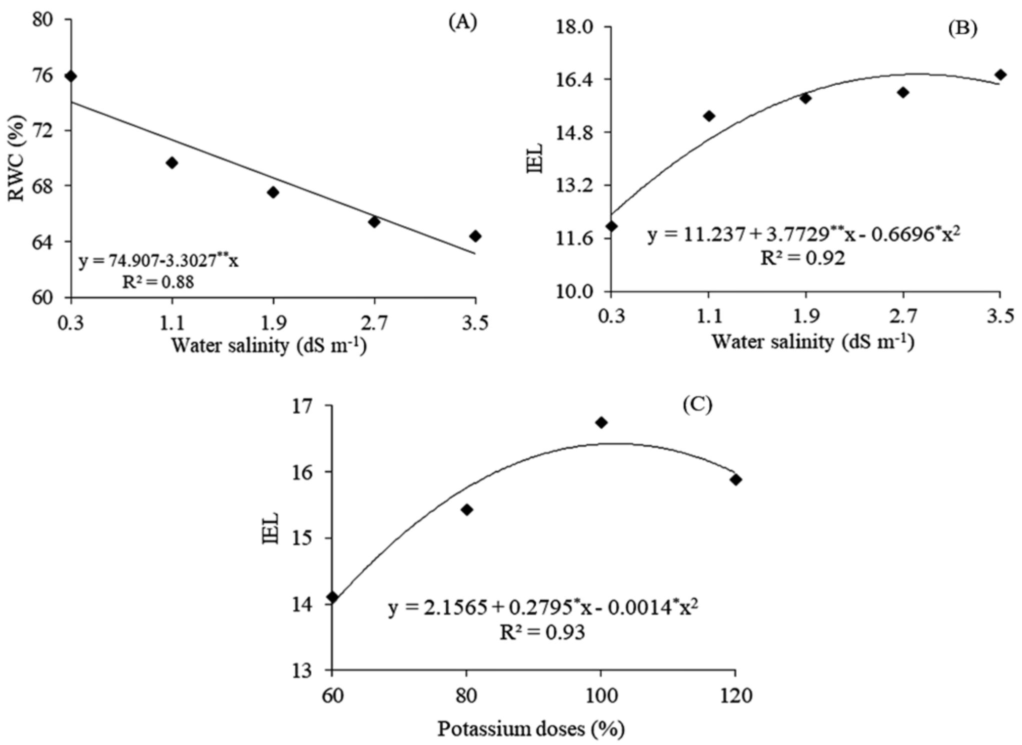

Figure 2 - Relative water content - RWC (A) and intercellular electrolyte leakage - IEL (B) in the leaf blade of 'BRS SC1' sour passion fruit plants as a function of water salinity levels, and IEL as a function of potassium doses (C), 60 days after transplanting.

* and ** significant at $P \leq 0.05$ and ≤ 0.01, respectively.

the maximum estimated value of Car, 4.017 µg mL^{-1}. Conversely, the lowest Car contents (2.682 µg mL^{-1}) were reported in plants irrigated using water with the lowest salinity level (0.3 dS m^{-1}).

The summary of the analysis of variance (Table 3) showed significant effects of salinity levels on stomatal conductance (*gs*), intercellular CO_2 concentration (*Ci*), transpiration (*E*), CO_2 assimilation rate (A), instantaneous carboxylation efficiency (*CEi*), and instantaneous water use efficiency (*WUEi*) of 'BRS SC1' sour passion fruit plants. Potassium doses did not significantly affect any of the variables analyzed. However, the interaction between the factors (SL × KD) significantly influenced all the variables studied, except for *CEi*.

The stomatal opening of sour passion fruit (Figure 4A) had the highest values (0.178 mol H_2O m^{-2} s^{-1}) when plants were irrigated with water of 0.3 dS m^{-1} and fertilized with 95% of the recommended dose of K_2O. However, with the increase in salt concentrations in irrigation water, there was a reduction in *gs*, and the lowest value was reported at ECw of 3.5 dS m^{-1} under fertilization with 60% of the recommended dose of K_2O, equal to 0.109 mol H_2O m^{-2} s^{-1}, resulting in a loss of 38.76% compared to the highest value observed.

A behavior similar to that of *gs* was observed in the transpiration of sour passion fruit (Figure 4B), with the maximum gains found at the lowest ECw and under fertilization with 88% of the recommended dose of K_2O (3.25 mmol H_2O m^{-2} s^{-1}), with reduction of 32.31% in this value when plants were irrigated with ECw of 3.5 dS m^{-1} and fertilized with the K_2O dose of 120% (2.20 mmol H_2O m^{-2} s^{-1}).

However, for the intercellular CO_2 concentration (Figure 4C), the lowest value (136.28 µmol CO_2 m^{-2} s^{-1}) was reported when sour passion fruit plants were irrigated with supply water and fertilized with 85% of the recommended dose of K_2O. The highest value was obtained at ECw of 3.5 dS m^{-1} and under 120% of the recommended dose of K_2O (225.28 µmol CO_2 m^{-2} s^{-1}), with a gain of 65.31% compared to the lowest value.

This response is based on the values observed in the carboxylation efficiency (Figure 4D), with the best values established at the lowest salinity and the highest one found in the combination between

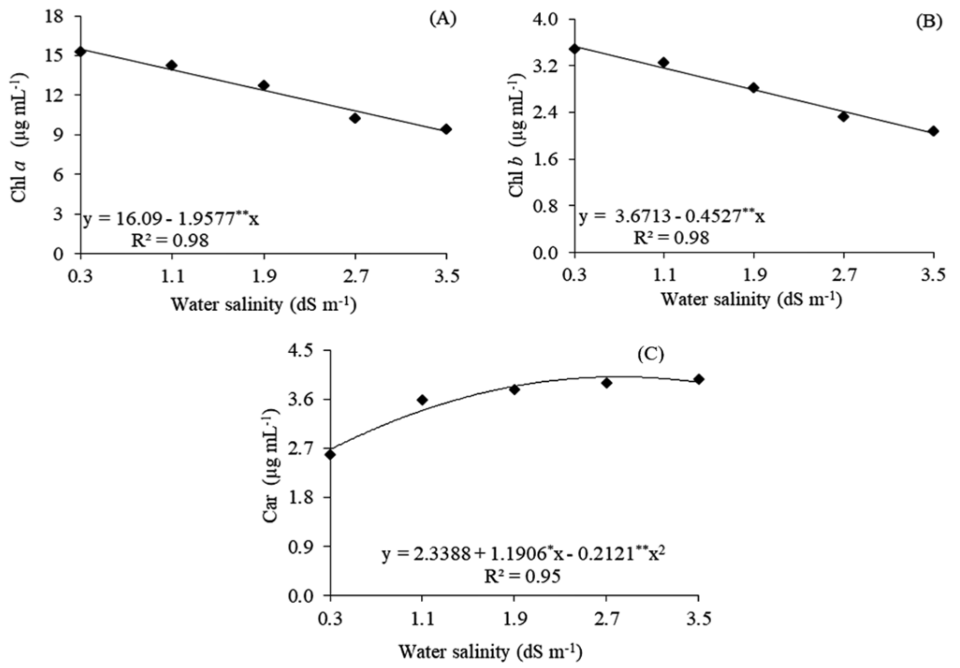

Figure 3 - Chlorophyll *a* - Chl *a* (A), chlorophyll *b* - Chl *b* (B), and carotenoids - Car (C) in the leaf blade of 'BRS SC1' sour passion fruit plants as a function of water salinity levels, 60 days after transplanting.

* and ** significant at $P \leq 0.05$ and ≤ 0.01, respectively.

ECw of 0.3 dS m^{-1} and K_2O dose of 85% [0.148 (µmol CO_2 m^{-2} s^{-1})(µmol CO_2 m^{-2} s^{-1})$^{-1}$]. Conversely, the lowest values were obtained at the highest salinity level, with maximum loss found at ECw of 3.5 dS m^{-1} and under 60% of the recommended dose of K_2O [0.066 (µmol CO_2 m^{-2} s^{-1})(µmol CO_2 m^{-2} s^{-1})$^{-1}$], resulting in the limitation of 55.41% of *CEi*.

The CO_2 assimilation rate of sour passion fruit plants was negatively influenced by irrigation with saline waters (Figure 5A). The maximum and minimum estimated values of 22.539 and 14.266 µmol CO_2 m^{-2} s^{-1} for *A* were obtained, respectively, in plants grown under ECw of 0.3 and 3.0 dS m^{-1}.

Table 3 - Summary of the analysis of variance for stomatal conductance (*gs*), intercellular CO_2 concentration (*Ci*), transpiration (*E*), CO_2 assimilation rate (A), instantaneous carboxylation efficiency (*CEi*), and instantaneous water use efficiency (*WUEi*) of 'BRS SC1' sour passion fruit plants cultivated with saline water and potassium doses, 60 days after transplanting.

Source of variation	DF	--------------------	----------Mean	squares----------	--------------------	--------------------
		gs	*Ci*	*E*	*A*	*CEi*	*WUEi*
Saline levels (SL)	4	0.021^{*}	9199.18^{**}	1.57^{*}	147.62^{*}	0.015^{**}	12.72^{*}
Linear regression	1	0.07^{**}	33533.63^{**}	4.88^{*}	484.12^{**}	0.055^{**}	5.76^{*}
Quadratic regression	1	0.007^{ns}	971.52^{ns}	1.17^{ns}	84.27^{*}	0.004^{*}	1.20^{ns}
Potassium doses (PD)	3	0.003^{ns}	184.75^{ns}	0.59^{ns}	18.64^{ns}	0.001^{ns}	2.43^{ns}
Linear regression	1	0.006^{ns}	4.81^{ns}	0.36^{ns}	47.52^{ns}	0.002^{ns}	4.04^{ns}
Quadratic regression	1	0.0002^{ns}	470.40^{ns}	0.20^{ns}	2.80^{ns}	0.0003^{ns}	0.51^{ns}
Interaction (SL × PD)	12	0.006^{*}	2579.78^{*}	0.87^{*}	31.76^{ns}	0.002^{*}	9.39^{ns}
Blocks	2	0.0009^{ns}	587.85^{ns}	6.08^{*}	40.74^{ns}	0.0005^{ns}	29.80^{*}
Residual	38	0.002	716.48	0.41	21.58	0.0008	2.92
CV(%)		25.18	14.90	12.51	13.69	14.76	11.85

DF - degrees of freedom; CV (%) - coefficient of variation; *significant at 0.05 probability level; ** significant at 0.01 probability level; ^{ns} not significant.

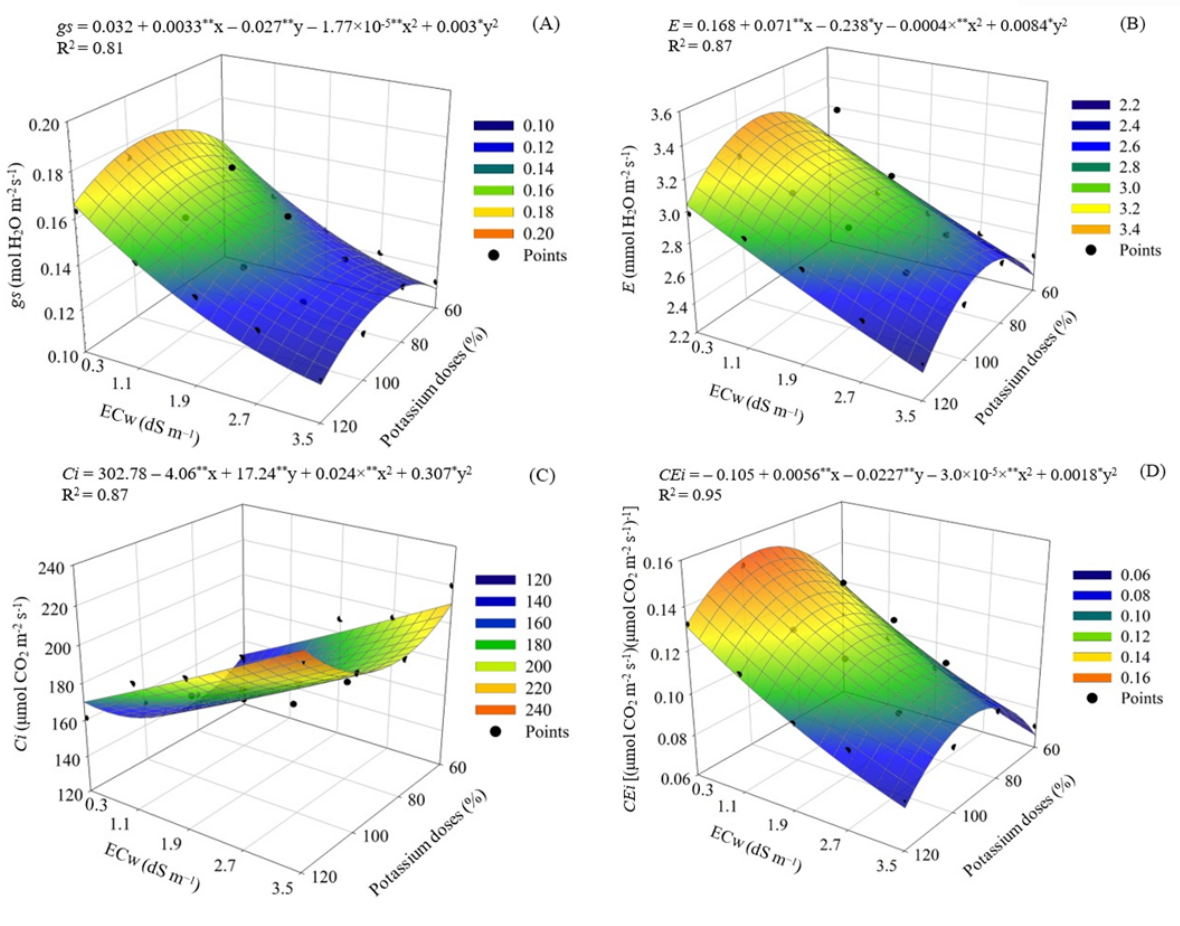

Figure 4 - Response surface for stomatal conductance - *gs* (A), transpiration - *E* (B), intercellular CO_2 concentration - *Ci* (C), and instantaneous carboxylation efficiency - *CEi* (D) of 'BRS SC1' sour passion fruit plants as a function of the interaction between electrical conductivity levels of irrigation water - ECw and potassium doses, 60 days after transplantation. X and Y - Electrical conductivity of water – ECw and potassium doses, respectively; * and ** significant at P≤0.05 and 0.01, respectively.

The instantaneous water use efficiency of 'BRS SC1' sour passion fruit plants decreased linearly with the increase in ECw levels (Figure 5B), with a reduction of 4.89% per unit increment in ECw. In relative terms, there was a decrease of 15.87% when comparing plants subjected to water salinity of 3.5 dS m^{-1} to those irrigated with ECw of 0.3 dS m^{-1}.

DISCUSSION

Under saline stress, plants suffer a systemic decrease in energy caused by reductions in photosynthetic rate and chlorophyll synthesis, as well as a redistribution of energy to defense and tolerance mechanisms (LIANG et al., 2022; SILVA et al., 2022). In the present study, the increase in the electrical conductivity of the irrigation water negatively affected the relative water content, the percentage of intercellular electrolyte leakage from the leaf blade, the chlorophyll synthesis, and the gas exchange of the sour passion fruit.

Conversely, the application of 85% of the recommended dose of K_2O was able to reduce the effects of salt stress on stomatal conductance, transpiration, internal CO_2 concentration, and instantaneous carboxylation efficiency of sour passion fruit plants.

Relative water content is an important variable to indicate the water status of plants under different environmental stresses, such as water and salt stresses because it represents the maximum amount of water that leaves can receive under total turgor (KHATAMI et al., 2022). The reduction in the relative water content in the leaf blade is a consequence of the restriction imposed by the osmotic effect, which reduces the absorption of water by the roots and induces stomatal closure, affecting transpiration and causing a decrease in water absorption, leading to low relative water content (POLASH et al., 2018).

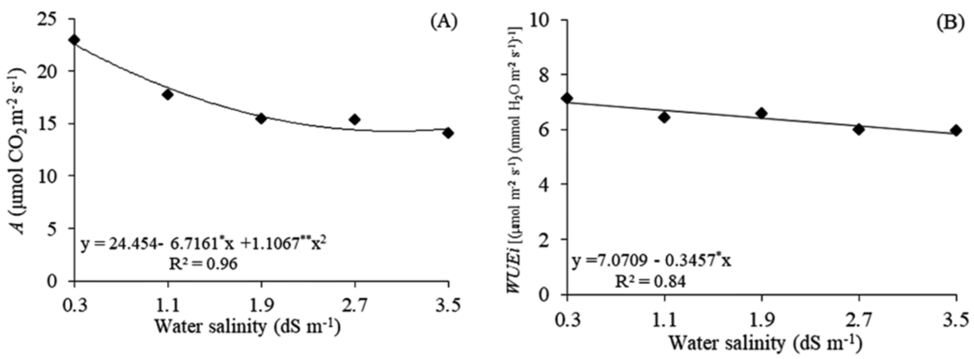

Figure 5 - CO_2 assimilation rate – *A* (A) and instantaneous water use efficiency – *WUEi* (B) of 'BRS SC1' sour passion fruit plants as a function of water salinity levels, 60 days after transplanting.
* and ** significant at P ≤ 0.05 and ≤ 0.01, respectively.

Intercellular electrolyte leakage can be induced by several factors, such as oxidative degradation of lipid bilayer or mechanical defects (DEMIDCHIK et al., 2014). Thus, lipid peroxidation damaged the cell membrane due to the accumulation of reactive oxygen species (ROS), causing oxidative stress because of the excess energy being directed to oxygen, generating several ROS including superoxide, hydrogen peroxide, hydroxyl radicals, and singlet oxygen (WU et al., 2017).

In a study evaluating cellular damage and the contents of photosynthetic pigments of sour passion fruit as a function of the cationic nature of irrigation water, LIMA et al. (2020a) concluded that irrigation with water of 3.0 dS m^{-1} containing Na^+ and $Na^+ + Ca^{2+}$ in its composition resulted in greater cellular damage in leaf tissues.

In this study, the application of potassium up to the dose of 100% of the recommendation promoted an increase in the percentage of intercellular electrolyte leakage of the sour passion fruit. The increase in electrolyte leakage in the leaf blade is mainly related to the efflux of K^+ from plant cells, which is mediated by the cationic conductance of the plasma membrane, including components with different activation kinetics and cationic selectivity. K^+ efflux induced by salt stress is a process with rapid activation, which leads to a significant decrease in K^+ activity in the cytosol (DEMIDCHIK et al., 2014).

The decrease in chlorophyll content has been considered a typical symptom of oxidative stress and can be attributed to the inhibition of synthesis or degradation by the chlorophyllase enzyme (SOARES et al., 2021). In addition, the reduction may occur due to slow synthesis or rapid degradation, being an indication that there was a photoprotection mechanism through the reduction of light absorbance, decreasing chlorophyll contents (TAÏBI et al., 2016).

According to SAYYAD-AMIN et al. (2016), lipid peroxidation and reactive oxygen species (ROS) play an essential role in damaging several photosynthetic membranes to which photosynthetic pigments were bound, also contributing to the reduction of their synthesis.

The increase in carotenoid levels as a function of saline stress, observed in the present study, evidences a mechanism of salinity tolerance, considering that, carotenoids have the potential to detoxify plants from the effects of reactive oxygen species. In addition, they dissipate excess energy through the xanthophyll cycle and can act as powerful chloroplast membrane stabilizers that partition between light-harvesting complexes and the lipid phase of thylakoid membranes, reducing membrane fluidity and susceptibility to lipid peroxidation (TAÏBI et al., 2016).

Sour passion fruit leaf gas exchange was negatively affected by exposure to salt stress. This result is a consequence of the effects of salt accumulation in the soil, which reduces osmotic potential and limits the absorption of water by the plant, leading to stomatal closure (Figure 4A) and reduced transpiration (Figure 4B) (FRANZISKY et al., 2021).

Similar results were observed in a study developed by ANDRADE et al. (2019), evaluating the gas exchange of sour passion fruit under saline stress (ECw ranging from 0.7 to 2.8 dS m^{-1}), reported reductions of 36.17% in *gs* and 29.48% in *E*, while comparing the plants irrigated with ECw of 2.8 dS m^{-1} with the control (0.7 dS m^{-1}).

The internal concentration of CO_2 increased as a function of the increase in the electrical conductivity of the water. In this case, the behavior is different from that of *gs* and *E*, which may be explained by limitations in the photosynthetic rate of passion fruit, due to phytotoxic damage arising from the accumulation of ions in the plant, leading to lower activity of RuBisCO and, perhaps, carbon consumption in Calvin's cycle (PAN et al., 2021).

The results of this research revealed that the increase in the electrical conductivity of the irrigation water compromised the instantaneous efficiency of the carboxylation. These results corroborated those reported by SILVA et al. (2019), who found that salinity compromises carbon utilization in cotton crop (*Gossypium hirsutum* L.).

In addition, the high availability of potassium by means of KCl can increase the toxic effects of salinity due to the availability of chloride in the soil solution (WANG et al., 2020), and doses lower than recommended bring benefits to plants under severe stress, as observed when using the recommended dose of K_2O under the highest water salinity, which showed gains in carboxylation efficiency of 28.92% in comparison to the lowest dose of K_2O and 57.12% in comparison to the lowest value of *CEi*. This showed the beneficial action of potassium on osmotic regulation in plants under salinity, contributing to nitrogen metabolism and antioxidant activity of the plant, resulting in the maintenance of the photosynthetic apparatus (AHANGER & AGARWAL, 2017; SHI et al., 2020).

The reduction in the CO_2 assimilation rate in plants cultivated under salt stress usually occurs due to stomatal and/or non-stomatal limitations. LIMA et al. (2020b), when evaluating the gas exchange of 'BRS Rubi do Cerrado' passion fruit as a function of irrigation with saline waters and potassium fertilization, in the seedling formation stage, also observed that the highest CO_2 assimilation rate was obtained in plants grown under ECw of 0.3 dS m^{-1}, with a marked reduction above this water salinity level.

The reduction in the CO_2 assimilation rate and stomatal closure of plants led to a decrease in water use efficiency, probably due to limitations of stomatal origin and non-stomatal factors. Unlike the results obtained in this study, LIMA et al. (2020b) evaluated the effects of irrigation with saline waters and potassium doses on the formation of seedlings of passion fruit cv. 'BRS Rubi do Cerrado' and observed that water salinity of up to 3.5 dS m^{-1} did not interfere in the instantaneous water use efficiency, at 40 days after sowing.

CONCLUSION

Irrigation using water with electrical conductivity above 0.3 dS m^{-1} reduces the relative water content, chlorophylls *a* and *b* contents, CO_2 assimilation rate, and instantaneous water use efficiency of 'BRS SC1' sour passion fruit plants.

Potassium doses of 100% of the recommendation (equivalent to 345 g per plant per year) increase the electrolyte leakage in the leaf blade of sour passion fruit plants.

The estimated dose of potassium of 85% of the recommendation (equivalent to 293 g per plant per year) mitigated the deleterious effects of salt stress on stomatal conductance, transpiration, internal CO_2 concentration, and instantaneous carboxylation efficiency of the sour passion fruit 'BRS SC1'.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally in the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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