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Scientific Article

Mineral composition of sour passion fruit cultivated under irrigation with saline water and potassium fertilization

Composição mineral de maracujazeiro-azedo cultivado sob irrigação com águas salinas e adubação potássica

Francisco J. da S. Paiva[1]*, Geovani S. de Lima[1], Vera L. A. de Lima[1], Weslley B. B. de Souza[1], Lauriane A. dos A. Soares[2], Francisco A. da Silva[1], Reynaldo T. de Fátima[1], Rafaela A. F. Torres[1]

[1]Post Graduate Program in Agricultural Engineering, Universidade Federal de Campina Grande, Campina Grande, PB, Brazil. [2]Academic Unit of Agricultural Sciences, Universidade Federal de Campina Grande, Pombal, PB, Brazil.

ABSTRACT - Salt stress is one of the main abiotic factors responsible for limiting agricultural production worldwide, especially in regions with a semi-arid climate, where climatic conditions intensify the effect of salts on plants. The objective of this study was to evaluate the mineral composition of sour passion fruit plants grown under irrigation with saline water and potassium fertilization in a semi-arid region of Brazil. The experiment was carried out under field conditions in São Domingos, PB, Brazil. A randomized block design was adopted, in a 5 × 4 factorial scheme, with five levels of electrical conductivity of irrigation water - ECw (0.3, 1.1, 1.9, 2.7 and 3.5 dS m^{-1}) and four potassium doses - KD (60, 80, 100 and 120% of the K_2O recommendation) with 3 replicates. There was an increase in sodium and chloride contents in the stem and leaves of sour passion fruit plants with the increase in ECw levels. Fertilization with 120% of the K_2O recommendation associated with irrigation using water with EC of up to 1.1 and 1.6 dS m^{-1} increased potassium content in the stem and leaves and leaf nitrogen content, respectively, in 'BRS Sol do Cerrado' sour passion fruit plants. Fertilization with 60% of the K_2O recommendation increased phosphorus content in the leaves of sour passion fruit plants under water salinity of up to 2.2 dS m^{-1}. In the leaves, nutrient contents varied according to the order of concentration N>Cl>P>Na>K, while in the stem the order was N>Cl>P>Na>K, at 160 days after transplanting.

Keywords: *Passiflora edulis* Sims. Ionic absorption. Salt stress. Osmoregulation.

RESUMO - O estresse salino é um dos principais fatores abióticos responsáveis pela limitação da produção agrícola em todo o mundo, especialmente em regiões de clima semiárido, onde as condições climáticas intensificam o efeito dos sais sob as plantas. Objetivou-se avaliar a composição mineral de plantas de maracujazeiro-azedo cultivado sob irrigação com água salina e adubação potássica em uma região Semiárida do Brasil. A pesquisa foi desenvolvida sob condições de campo em São Domingos-PB. Adotou-se o delineamento em blocos casualizados, em esquema fatorial 5 × 4, sendo cinco níveis de condutividade elétrica da água de irrigação - CEa (0,3; 1,1; 1,9; 2,7 e 3,5 dS m^{-1}) e quatro doses de potássio - DK (60; 80; 100 e 120% da recomendação de K_2O) com 3 repetições. Houve aumento nos teores de sódio e cloreto no caule e folhas das plantas de maracujazeiro-azedo com o incremento nos níveis de CEa. A adubação com 120% da recomendação de K_2O associada à irrigação com água de CE de até 1,1 e 1,6 dS m^{-1}, aumentou os teores de potássio no caule e folhas e nitrogênio foliar, respectivamente, nas plantas de maracujazeiro-azedo 'BRS Sol do Cerrado'. A adubação com 60% da recomendação de K_2O aumentou os teores de fósforo nas folhas das plantas de maracujazeiro-azedo sob salinidade da água de até 2,2 dS m^{-1}. Nas folhas, os teores de nutrientes variaram segundo a ordem de concentração N>Cl>P>Na>K, enquanto no caule, seguiu a ordem N>Cl>P>Na >K, aos 160 dias após o transplantio.

Palavras-chave: *Passiflora edulis* Sims. Absorção iônica. Estresse salino. Osmorregulação.

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***Corresponding author:**
<je.an_93@hotmail.com>

INTRODUCTION

Salinity is one of the main abiotic stresses responsible for limiting agricultural production worldwide. This problem can be further exacerbated when crops are grown in regions with a semi-arid climate, due to the action of climatic factors, such as high temperatures and low rainfall. In addition to adverse environmental conditions, anthropogenic factors such as excessive use of fertilizers, agrochemicals, and the use of water with moderate levels of salts in irrigation end up intensifying the salinization of cultivated areas (SELEIMAN et al., 2022). Salt stress imposes limitations on plants, preventing them from expressing their full genetic potential and resulting in a significant decline in production (LIMA et al., 2023a).

The stress caused by salinity mainly affects the balance of soil water potential and ionic distribution through the plasma membrane of root cells, causing nutritional imbalances and cytotoxicity due to oxidative stress (ISAYENKOV; MAATHUIS, 2019), due to the increase in the accumulation of reactive oxygen species (ROS), such as hydrogen peroxide (H_2O_2) in plant tissues, also negatively affecting photosynthesis, protein synthesis and, consequently, crop growth, development and yield (SHALABY; FARAG; IBRAHIM, 2023).

Salinity influences the dynamics of nutrient uptake by plants. Salt stress denatures proteins and enzymes that regulate iron (Fe) absorption, which, when reduced, limits the synthesis of photosynthetic pigments (LIU et al., 2022). In addition, sodium inhibits the uptake of K and other nutrients by root cells, inducing irregular plant metabolism that is toxic to enzymes at the genetic level (TIWARI et al., 2023). Under saline conditions, processes such as stomatal opening and closing and the activity of enzymes involved in carbon dioxide fixation are negatively affected, causing reductions in photosynthetic rate (NEGRÃO; SCHMÖCKEL; TESTER, 2017).

In this context, implementing management strategies becomes indispensable for agricultural production in the semi-arid region of Northeast Brazil, and potassium fertilization stands out as a promising approach to mitigate the deleterious effects of salinity on plants. Potassium (K) potentially reduces the damage caused by salt stress in plants, through the reduction of ROS induced by osmotic stress, strengthening the activity of antioxidant enzymes and reestablishing the efficiency of nitrogen use by plants (TITAL et al., 2021). K also contributes to the tolerance of plants to salinity by competing with sodium (Na^+) in binding and maintaining plant water status (CAPULA-RODRÍGUEZ et al., 2016).

Thus, it is essential to conduct studies aimed at evaluating the effects of potassium fertilization as a salt stress-mitigating factor on plants, especially in crops of great economic relevance, such as sour passion fruit. In this context, the objective of this study was to evaluate the mineral composition of sour passion fruit plants cultivated under irrigation with saline water and potassium fertilization.

MATERIAL AND METHODS

The experiment was carried out between November 2021 and July 2022 in the fruit growing sector, located at the 'Rolando Enrique Rivas Castellón' experimental farm, belonging to the Center for Sciences and Agri-Food Technology of the Federal University of Campina Grande, located in the city of São Domingos, PB, Brazil, whose coordinates are: 06º48'50" S latitude and 37º56'31" W longitude, at an altitude of 190 m. Agrometeorological data were obtained from the weather station located in the district of São Gonçalo, in the city of Sousa, PB, as shown in Figure 1.

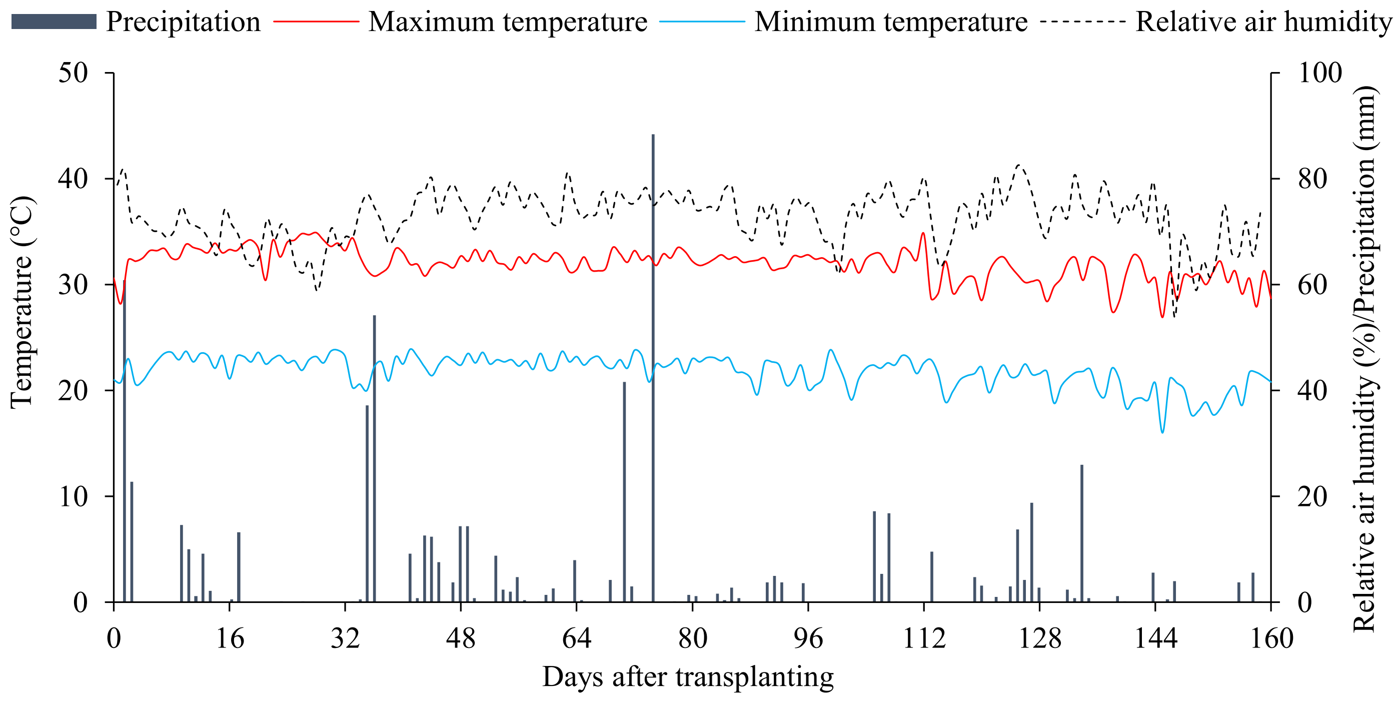


Figure 1. Data of maximum and minimum temperature (ºC), relative humidity (%) and precipitation (mm) during the experimental period.

A randomized block design was used, in a 5 × 4 factorial scheme, whose treatments were obtained by combining five levels of electrical conductivity of irrigation water - ECw (0.3, 1.1, 1.9, 2.7 and 3.5 dS m^{-1}) and four potassium doses - KD (60, 80, 100 and 120% of K_2O as recommended by Costa et al. (2008), with 3 replicates, totaling 60 experimental units. ECw levels were established based on a study conducted by Lima et al. (2020). The 100% dose corresponded to 345 g of K_2O per plant per year (COSTA et al., 2008), with applications started at 20 days after transplanting (DAT).

The sour passion fruit genotype 'BRS Sol do Cerrado' (BRS SC1) was used in the present study, based on the levels of tolerance to salt stress obtained by Lima et al. (2023a). Seedlings were formed in a protected environment, arranged on benches close to the experimental area, using polyethylene bags with dimensions of 15 × 20 cm, filled with a substrate composed of soil and aged cattle manure, in the proportion of 2:1 m^3 (on a volume basis), respectively.

Three seeds were sown per bag at 0.5 cm depth. After seedling emergence, thinning was carried out, leaving only one plant per bag. During the formation of the seedlings, irrigation was performed using water with lower electrical conductivity level ($ECw = 0.3$ dS m^{-1}).

The experiment was conducted in the field, using pots adapted as drainage lysimeters, with a capacity for 100 L, filled with 110 kg of a *Neossolo Flúvico Ta Eutrófico* (Fluvent), with loamy sand texture, from a private property close to the experimental area, whose physical-hydraulic and chemical characteristics were determined according to the methodology of Teixeira et al. (2017), as shown in Table 1.

Table 1. Chemical and physical characteristics of the soil used in the experiment, before the application of the treatments.

Physical-hydraulic, chemical and salinity characteristics								
pH (H_2O)	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
(1:2.5)	g kg^{-1}	(mg kg^{-1})	……… cmol$_c$ kg^{-1} ………					
6.01	0.21	0.53	0.12	0.05	3.00	2.44	0.00	0.69
EC_{se}	CEC	SAR	ESP	Sand	Silt	Clay	Moisture (%)	
(dS m^{-1})	cmol$_c$ kg^{-1}	(mmol $L^{-1})^{0.5}$	%	……… (g kg^{-1}) ………			0.33 atm	15.0 atm
0.71	6.25	0.61	0.8	75.65	20.01	4.34	33.57	5.01
Textural class		Total porosity (%)		33.42 kPa[1]	1519.5 kPa[2]	PD (g/cm^3)		BD (g/cm^3)
Loamy sand		50.54		13.57	5.01	2.65		1.31

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; EC_{se} - Electrical conductivity of saturation extract; CEC - Cation exchange capacity; SAR - Sodium adsorption ratio of saturation extract; ESP - Exchangeable sodium percentage; [1,2] corresponding to soil moisture at field capacity and at permanent wilting point, respectively; BD - Bulk density; PD - Particle density.

Plants were cultivated in a vertical trellis system, composed of smooth wire of galvanized steel No. 12, installed at 1.2 m height above the lysimeter soil surface. The plants were trained using nylon twine, and when they exceeded 10 cm above the trellis, the apical bud was pruned to stimulate the growth of secondary branches, which were grown in opposite directions until they reached 1.50 m length each. After the secondary branches reached the pre-established length, the apical bud was pruned to stimulate the growth of tertiary branches, which were grown until they reached 30 cm from the soil surface of the experimental area, in order to avoid possible contamination by contact with the soil. The spacing adopted was 3.0 m between plants and 2.5 m between rows.

The seedlings were transplanted to the lysimeters at 60 days after sowing, when they started producing tendrils and reached an average height of 50 cm. During the first 30 DAT, all plants were irrigated using water with electrical conductivity of 0.3 dS m^{-1} and from 31 DAT, irrigations sing water with the different levels of electrical conductivity were initiated, according to the established treatments.

Urea (45% N), single superphosphate (20% P_2O_5; 16% Ca^{2+}; 10% S) and potassium sulfate (51.5% K_2O) were used as sources of nitrogen, phosphorus and potassium, respectively. Nitrogen and potassium fertilization was split and applied monthly throughout the crop cycle, adopting ratios (N/K) of 1/1 in the flowering stage, 1/2 in the fruiting stage and 1/3 until the end of the harvest. Phosphorus was applied only once as basal and incorporated into the soil during lysimeter filling, as recommended by Costa et al. (2008).

Micronutrient application was performed fortnightly using Dripsol® micro (Mg^{2+} = 1.1%; B = 0.85%; Cu (Cu-EDTA) = 0.5%; Fe (FeEDTA) = 3.4%; Mn (Mn-EDTA) = 3.2%; Mo = 0.05%; Zn = 4.2%; containing 70% chelating agent EDTA) at a concentration of 1 g L^{-1}, by foliar spraying. During micronutrient applications, Haiten® adhesive spreader was added at a concentration of 0.15 mL L^{-1}. The water used for irrigation came from an artesian well located in the experimental area, whose chemical composition is presented in Table 2.

Table 2. Chemical characteristics of the water of lowest salinity used in the experiment.

Ca^{+2}	Mg^{+2}	Na^+	K^+	SO_4^{2-}	HCO_3^-	CO_3^-	Cl^-	EC dS m^{-1}	pH	SAR (mmol$_c$ $L^{-1})^{0.5}$
------ (mmol$_C$ L^{-1}) ------										
0.17	0.61	1.41	0.29	0.18	0.81	0.00	1.26	0.22	7.10	2.26

CE - electrical conductivity. SAR - sodium adsorption ratio.

To obtain the electrical conductivity levels of 0.3, 1.1, 1.9, 2.7 and 3.5 dS m^{-1}, iodine-free sodium chloride (NaCl) was added to the well water, and the concentrations in the available water were adjusted considering the relationship between ECw and salt concentration (RICHARDS, 1954), according to Equation 1:

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

Where:
C = Concentration of salts to be applied (mg L^{-1});
ECw = Electrical conductivity of water (dS m^{-1}).

Irrigation was applied by a drip system, with each plant supplied by two pressure-compensating drippers with flow rate of 10 L.h^{-1}. Irrigations were carried out daily, starting at 7:00 a.m., applying in each lysimeter the volume corresponding to that obtained by the water balance, and the volume of water to be applied to the plants was determined by Equation 2:

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

Where:
VI = Volume of water to be used in the next irrigation event (L);
Va = volume applied in the previous irrigation event (L);
Vd = Volume drained (L);
LF = leaching fraction of 0.2, applied every 15 days to reduce the accumulation of salts in the root zone.

Weed control was performed by manual weeding operations, between the rows of the drainage lysimeters and around the plant collar. Pests and diseases were controlled preventively, and the products used were: Ridomil Gold®, a fungicide composed of Metalaxyl-M (40 g kg^{-1}) and Mancozeb (640 g kg^{-1}), at a dose of 2.5 g L^{-1}, and the insecticides Cyptrin 250 CE® (Cypermethrin (250 g L^{-1})) at a dose of 1 mL L^{-1}, and Connect® (Beta-cyfluthrin (12.5 g L^{-1}) and Imidacloprid (100 g L^{-1})) at a dose equivalent to 750 mL ha^{-1} of the commercial product.

The effects of the different treatments were evaluated by determining the accumulation of nitrogen (N), phosphorus (P), potassium (K), sodium (Na), chloride (Cl) and sulfur (S) in leaf and stem tissues of sour passion fruit plants. For this, leaves from the middle third of the tertiary branches were collected from plants at full fruiting stage (at 160 DAT), and then the samples were dried in a forced air circulation oven at 65 ºC for 72 hours. After drying, the plant material was crushed in a Wiley mill and analyzed to determine the above-mentioned nutrients.

To determine the nutrient contents, nitric (P, Na, K, S) and sulfuric (N) digestions were carried out according to the methodology of Silva (2009). Nitrogen determination was performed by the Kjeldahl method and, after distillation, the data were obtained by titration. Na and K contents were determined by the flame photometry technique, and P content was determined by the molybdate-vanadate colorimetric method in the spectrophotometer.

The multivariate structure of the results was assessed by principal component analysis (PCA), synthesizing the amount of relevant information contained in the original dataset in a smaller number of dimensions. This resulted from linear combinations of the original variables, derived from the eigenvalues ($\lambda \geq 1.0$) in the correlation matrix, which explained more than 10% of the total variance (GOVAERTS et al., 2007).

From the reduction of the dimensions, the original data of the variables of each component were subjected to multivariate analysis of variance (MANOVA) by the test of Hotelling et al. (1947) at 0.05 probability level for the levels of electrical conductivity of irrigation water, doses of potassium fertilization and their interactions. Only variables with a correlation coefficient equal to or greater than 0.65 were maintained for each principal component (PC) (HAIR et al., 2009). Statistical analyses were performed using Statistica v. 7.0 software.

Data that did not obtain a correlation coefficient above 0.65 were initially subjected to the Shapiro-Wilk normality test to check their distribution. Subsequently, analyses of variance were applied using the F test ($p \leq 0.05$) and, when significant, linear and quadratic polynomial regression analysis was performed for the factors electrical conductivity of irrigation water and doses of potassium fertilization, using the statistical software SISVAR - ESAL version 5.7 (FERREIRA, 2019).

RESULTS AND DISCUSSION

The multidimensional space of the original variables was reduced to two principal components (PC1 and PC2) with eigenvalues greater than $\lambda \geq 1.0$ (KAISER, 1960). Together, the eigenvalues and percentage of explained variance for each component (Table 3) represented 79.33% of the total variation. PC1 explained 49.63% of the total variance, represented by most variables, and PC2 represented 29.7% of the remaining variance.

There was a significant effect ($p \leq 0.01$) of the interaction between the levels of electrical conductivity of irrigation water and potassium doses (ECw × KD) for PC1 and PC2 (Table 3). When analyzed individually, both factors also had a significant effect ($p \leq 0.01$) on the principal components.

Effects of the treatments and the variables are shown in Figures 2A and 2B for the first and second principal components (PC1 and PC2). In PC1, there is a possible interaction between the levels of electrical conductivity of irrigation water and potassium doses (ECw × KD). The correlation coefficients were equal to or greater than 0.85 for the Cl_{Leaf} and Na_{Leaf} contents as well as for the Na_{Stem} content of sour passion fruit plants.

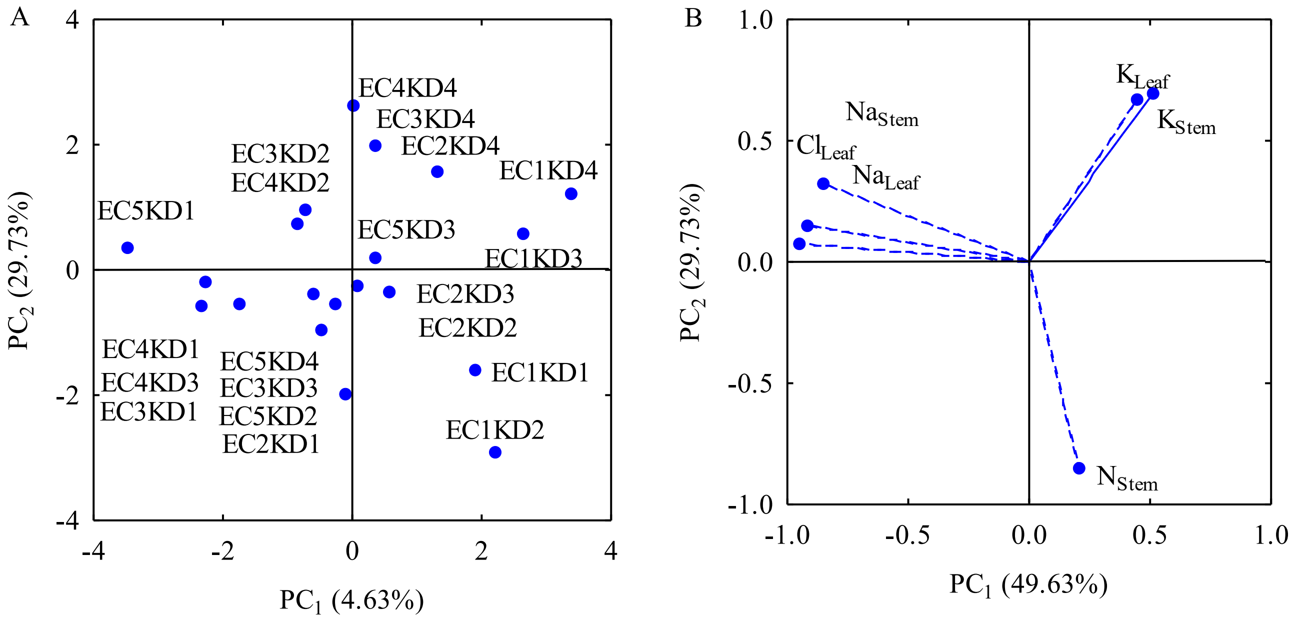
Table 3. Eigenvalues, percentage of total variance explained in the multivariate analysis of variance (MANOVA), probability of significance by Hotelling test ($p \leq 0.01$) for the factors electrical conductivity of irrigation water (ECw), potassium doses (KD) and ECw × KD interaction, and the correlation coefficients (r) between original variables and the principal components.

	Principal Components (PCs)	
	PC_1	PC_2
Eigenvalues (λ)	2.97	1.78
Percentage of total variance (S^2%)	49.63	29.7
Hotelling test (T^2) for electrical conductivity of water (ECw)	0.01	0.01
Hotelling test (T^2) for potassium doses (KD)	0.01	0.01
Hotelling test (T^2) for interaction (ECw × KD)	0.01	0.01

PCs	Correlation coefficients					
	Cl_{Leaf}	Na_{Leaf}	K_{Leaf}	Na_{Stem}	K_{Stem}	N_{Stem}
PC_1	-0.91	-0.95	0.44	-0.85	0.51	0.20
PC_2	0.15	0.07	0.67	0.32	0.70	-0.84

Treatments	Mean values					
	Cl_{Leaf}	Na_{Leaf}	K_{Leaf}	Na_{Stem}	K_{Stem}	N_{Stem}
	---------- g kg^{-1} ----------					
EC1KD1	17.28±0.77	0.98±0.05	22.92±2.57	0.81±0.04	9.46±0.86	22.80±0.7
EC1KD2	15.95±1.54	0.88±0.05	17.59±0.24	0.83±0.03	10.01±1.12	36.43±2.9
EC1KD3	19.50±1.02	0.99±0.02	35.31±1.24	0.79±0.11	16.24±0.90	17.10±1.2
EC1KD4	15.07±0.85	0.65±0.10	36.84±3.44	0.73±0.03	18.16±5.19	12.70±1.2
EC2KD1	32.79±0.51	1.69±0.007	14.84±0.30	0.91±0.01	11.64±0.99	29.90±0.9
EC2KD2	25.70±3.07	1.42±0.05	24.89±0.01	1.41±0.04	11.39±0.76	19.61±2.4
EC2KD3	28.36±1.28	1.57±0.05	28.21±3.86	1.32±0.01	9.49±0.10	15.30±1.3
EC2KD4	22.60±4.09	1.37±0.06	36.86±2.07	1.38±0.06	21.56±0.98	7.81±0.1
EC3KD1	31.91±2.05	2.36±0.05	11.86±0.05	1.43±0.07	9.31±1.06	8.02±2.2
EC3KD2	28.36±0.28	1.64±0.09	22.96±1.59	2.18±0.12	12.59±0.90	4.95±0.6
EC3KD3	30.47±0.86	1.76±0.06	26.59±0.27	1.33±0.07	9.61±0.34	19.12±2.1
EC3KD4	26.59±2.54	1.57±0.09	34.59±1.42	1.73±0.09	14.74±0.62	2.51±0.02
EC4KD1	31.31±1.56	2.19±0.11	24.44±2.03	2.68±0.17	6.11±0.60	13.30±2.3
EC4KD2	34.12±1.79	1.94±0.05	12.61±2.67	2.07±0.05	11.51±0.51	18.61±1.1
EC4KD3	33.68±1.03	2.14±0.10	36.54±0.54	2.41±0.17	9.55±0.38	13.54±2.4
EC4KD4	31.61±2.82	1.70±0.08	29.86±1.22	2.05±0.06	15.11±3.11	5.42±1.0
EC5KD1	44.76±0.26	2.67±0.005	24.29±2.20	2.72±0.14	9.79±0.53	17.52±1.4
EC5KD2	28.36±1.02	1.84±0.11	23.44±1.31	1.73±0.06	8.16±0.11	24.93±3.2
EC5KD3	28.36±2.05	1.46±0.11	31.16±0.37	1.57±0.07	12.09±0.12	17.91±2.6
EC5KD4	29.25±0.51	1.27±0.03	28.39±0.24	2.18±0.02	8.19±0.47	14.70±0.7

EC - Electrical conductivity of irrigation water, EC1 (0.3 dS m^{-1}); EC2 (1.1 dS m^{-1}); EC3 (1.9 dS m^{-1}); EC4 (2.7 dS m^{-1}); EC5 (3.5 dS m^{-1}); KD - potassium fertilization doses, KD1 - 60% of the K_2O recommendation; KD2 - 80% of the K_2O recommendation; KD3 - 100% of the K_2O recommendation; KD4 - 120% of the K_2O recommendation; Cl_{Leaf} - leaf chloride; Na_{Leaf} - leaf sodium; K_{Leaf} - leaf potassium; Na_{Stem} - stem sodium; K_{Stem} - stem potassium; and N_{Stem} - stem nitrogen.



EC - Electrical conductivity of irrigation water, EC1 (0.3 dS m^{-1}); EC2 (1.1 dS m^{-1}); EC3 (1.9 dS m^{-1}); EC4 (2.7 dS m^{-1}); EC5 (3.5 dS m^{-1}); KD – potassium fertilization doses, KD1 (60% of the K_2O recommendation); KD2 (80% of the K_2O recommendation); KD3 (100% of K_2O recommendation); KD4 (120% of K_2O recommendation).

Figure 2. Two-dimensional projection of the scores of the principal components for the factors levels of electrical conductivity of irrigation water – ECw and potassium doses – KD of sour passion fruit (A) and of the variables analyzed (B) in the two principal components (PC1 and PC2).

The highest contents of Cl_{Leaf}, Na_{Stem} and Na_{Leaf} were obtained in plants cultivated using irrigation water with EC of 3.5 dS m^{-1} and potassium fertilization with 60% of the K_2O recommendation (EC5KD1), whose values were 44.76 g kg^{-1}, 2.72 g kg^{-1} and 2.67 g kg^{-1}, respectively (Table 3). The lowest contents of Cl_{Leaf}, Na_{Stem} and Na_{Leaf} were obtained in plants subjected to the lowest ECw level (0.3 dS m^{-1}) and potassium dose corresponding to 120% of the recommendation of K_2O (EC1KD4), whose values were 15.07 g kg^{-1}, 0.73 g kg^{-1} and 0.65 g kg^{-1}, respectively, i.e., there were reductions of 66.33% (29.69 g kg^{-1}), 72.95% (1.99 g kg^{-1}) and 75.62% (2.02 g kg^{-1}), respectively, when comparing the values obtained in plants subjected to the EC1KD4 treatment and those of plants under EC5KD1.

The increase in Na_{Leaf}, Cl_{Leaf} and Cl_{Stem} contents of sour passion fruit plants due to the increase in the electrical conductivity of irrigation water can be explained by the loss of the selective capacity of the cell membrane of the plants subjected to abiotic stress conditions, such as salinity, culminating in the accumulation of ions in the intercellular medium (FERNANDES; SOUZA, 2006).

Lima et al. (2015) evaluated the growth, sodium content, chlorine content and ionic ratio in castor bean under salt stress (ECw ranging from 0.3 to 3.9 dS m^{-1}) and nitrogen fertilization (70, 100, 130 and 160% of the recommendation – 100 mg N kg^{-1} of soil) and also found that the increase in irrigation water salinity resulted in increments in the sodium and chloride contents in leaves and stems, at 120 days after sowing.

Based on the results obtained in PC2, the eigenvalues for the leaf and stem potassium contents, as well as stem nitrogen content of sour passion fruit plants, were consistently equal to or greater than 0.67 (Table 3).

The highest K_{Stem} and K_{Leaf} contents were obtained in plants irrigated with 1.1 dS m^{-1} water and potassium fertilization with 120% of the K_2O recommendation (EC2KD4), equivalent to 21.56 g kg^{-1} and 36.86 g kg^{-1}, respectively (Table 3). The lowest K_{Stem} content was 6.11 g kg^{-1}, when plants were subjected to water salinity of 2.7 dS m^{-1} and fertilization with 60% K_2O, which represents a reduction of 93.13% (3.39 g kg^{-1}) compared to the EC2KD4 treatment. In turn, in the leaves (K_{Leaf}), the lowest value (11.86 g kg^{-1}) was observed when the level of electrical conductivity of irrigation water was increased to 1.9 dS m^{-1}, and potassium fertilization with 60% K_2O (EC3KD1), which is equivalent to a reduction of 37.87% compared to the EC2KD4 treatment (Table 3).

In this study, the K_{Leaf} contents of all plants that received fertilization equivalent to 100 and 120% of the K_2O recommendation, regardless of the level of electrical conductivity of irrigation water (Table 3), are within the range considered ideal by Diniz et al. (2020), which is 25 to 35 g kg^{-1}. On the other hand, plants that received potassium fertilization at levels below the recommended (60 and 80% of K_2O) were deficient in K in the leaf tissues. The increase in sodium concentration in the root zone can reduce the amount of potassium available to plants, due to the competitive absorption relationship between these two ions (HOSSEINI et al., 2023). In addition, with the limitation in K availability by the lowest doses, the reductions in K_{Leaf} contents observed may be associated with the translocation of potassium from older leaves to fruits, which starts to behave as a sink, given the ability of this nutrient to move within the plant (MELO et al., 2020).

Freire, Nascimento and Medeiros (2020) evaluated the nutrient contents in passion fruit seedlings under water salinity (0.5 to 3.5 dS m^{-1}) and the use of cow urine and found that the increase in the electrical conductivity of irrigation water, from 0.5 to 3.5 dS m^{-1}, reduced the leaf potassium (K^+) contents by 26.1% and 28.9% in yellow passion fruit (*Passiflora edulis f. flavicarpa* Deg) and purple passion fruit (*P. edulis* Sims), respectively.

Regarding the N_{Stem} contents, the highest value (36.43 g kg^{-1}) was reached in plants cultivated under irrigation with water of 0.3 dS m^{-1} and potassium fertilization with 80% of the K_2O recommendation (EC1KD2), and the lowest value (2.51 g kg^{-1}) was obtained when plants were irrigated using water with electrical conductivity of 2.7 dS m^{-1} and subjected to fertilization with a dose equivalent to 120% of the K_2O recommendation (EC3KD4) (Table 3), representing a reduction in nitrogen contents of 93.13% (33.95 g kg^{-1}) in the EC1KD2 treatment compared to EC3KD4.

Salinity causes changes in soil nutrient dynamics, negatively interfering with the availability and absorption of essential elements, such as potassium (K^+), calcium (Ca^{2+}), and nitrogen (N), and resulting in the accumulation of sodium (Na^+) and chlorine (Cl^-) ions in plant tissues (BOURAS et al., 2023). The increase in sodium and chloride contents in plants leads to a reduction in nitrogen contents, due to antagonistic relationships with the available forms of N in plants, such as ammonium and nitrate (ROY; CHOWDHURY, 2020).

There was a significant effect of the interaction between the factors (ECw × KD) on leaf nitrogen (N_{Leaf}), stem chloride (Cl_{Stem}) and stem phosphorus (P_{Stem}) and leaf phosphorus (P_{Leaf}) contents of 'BRS Sol do Cerrado' sour passion fruit plants, at 160 days after transplanting (Table 4).

Table 4. Summary of the analysis of variance for the of leaf nitrogen (N_{Leaf}), stem chloride (Cl_{Stem}), stem phosphorus (P_{Stem}), leaf phosphorus (P_{Leaf}), stem sulfur (S_{Stem}) and leaf sulfur (S_{Leaf}) contents of 'BRS Sol do Cerrado' sour passion fruit plants cultivated under salinity of irrigation water (ECw) and potassium fertilization (KD), at 160 days after transplanting.

Sources of variation	DF	Mean squares					
		N_{Leaf}	Cl_{Stem}	P_{Stem}	P_{Leaf}	S_{Stem}	S_{Leaf}
Electrical conductivity of water (ECw)	4	11.65^{**}	85.90^{**}	1.15^{**}	3.47^{**}	622.91^{ns}	16.14^{ns}
Linear Regression	1	12.63^{**}	333.53^{**}	0.05^{ns}	2.24^{**}	250.99^{ns}	7.05^{ns}
Quadratic Regression	1	28.86^{**}	9.97^{**}	1.83^{*}	7.60^{**}	46.96^{ns}	16.18^{ns}
Potassium doses (KD)	3	0.11^{ns}	31.08^{**}	3.15^{**}	1.54^{**}	81.07^{ns}	0.90^{ns}
Linear Regression	1	0.01^{ns}	15.05^{**}	5.03^{**}	1.40^{*}	240.59^{ns}	0.00^{ns}
Quadratic Regression	1	0.00^{ns}	63.05^{**}	0.31^{ns}	0.10^{ns}	2.15^{ns}	2.57^{ns}
Interaction (ECw × KD)	12	1.35^{**}	4.32^{**}	1.81^{**}	1.32^{**}	466.31^{ns}	16.10^{ns}
Block	2	0.50^{**}	1.93	0.83	0.49	1.47	27.96
Residual	38	0.36	1.05	0.27	0.29	15.97	18.77
CV (%)		15.41	10.04	22.35	19.10	14.50	7.83

DF - degrees of freedom; CV (%) - coefficient of variation; *significant at 0.05 probability level; ** significant at 0.01 probability level; ns not significant, by the F test ($p<0.05$).

For the N_{Leaf} contents of 'BRS Sol do Cerrado' sour passion fruit, the maximum estimated values of 50.4, 47.8, 48.3 and 54.0 g kg^{-1} were obtained in plants that received irrigation with ECw of 1.8, 1.4, 1.7 and 1.6 dS m^{-1} and fertilization with doses of 60, 80, 100 and 120% of the K_2O recommendation, respectively (Figure 3A), with reductions of 47.22, 45.18, 51.34 and 33.14%, respectively, as the ECw levels increased. In this context, the sour passion fruit plants were within the sufficiency range (40 to 50 g kg^{-1}) established by Malavolta, Vitti and Oliveira (1997).

Nitrogen contents in plants can be negatively affected by the antagonistic interaction between nitrate and chloride present in the soil solution. Bouras et al. (2023), when evaluating the use of saline water irrigation (0.7 to 12 dS m^{-1}) and phosphorus fertilization (85, 102 and 120 g P_2O_5 ha^{-1}) in wheat (*Triticum aestivum*), found that salinity significantly reduced N contents by 20, 15 and 25%, respectively, under salinity levels of 4, 8 and 12 dS m^{-1} compared to the control plants.

Cl_{Stem} contents increased linearly by 2.50, 1.54 and 2.38 g kg^{-1} per unit increment of ECw in plants that received potassium doses equivalent to 60, 80 and 100% of the K_2O recommendation, respectively (Figure 3B). The increase in salt concentration in the root zone causes changes in the ionic selectivity of plants during the absorption of the soil solution. Thus, the increase in Cl_{Stem} contents results from the high concentration of this element in the irrigation water. When comparing plants irrigated with 3.5 dS m^{-1} water to those cultivated under ECw of 0.3 dS m^{-1} and fertilization with 60, 80 and 100% K_2O, there were increments in the Cl_{Stem} contents of 131.69, 59.44 and 96.55 g kg^{-1}, respectively. On the other hand, when potassium doses equivalent to 120% of the K_2O recommendation were used, the maximum estimated value of 12.50 g kg^{-1} was reached in plants irrigated with irrigation water of 3.5 dS m^{-1}.

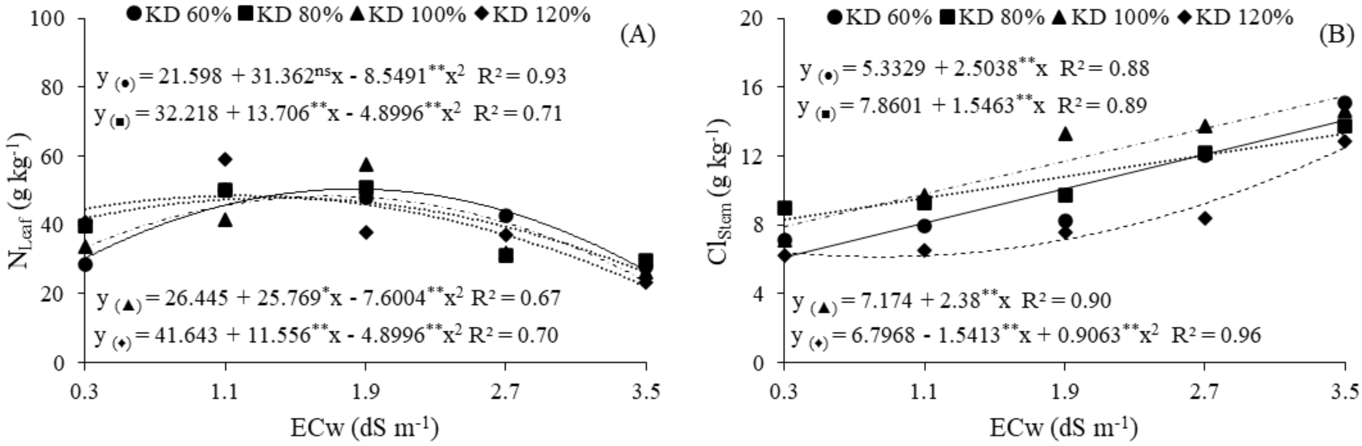


Figure 3. Leaf nitrogen – N_{Leaf} (A) and stem chloride – Cl_{Stem} (B) contents of 'BRS Sol do Cerrado' sour passion fruit plants as a function of the interaction between the levels of electrical conductivity of irrigation water – ECw and potassium doses – KD, at 160 days after transplanting. ^{ns}, ** and * represent, respectively, non-significant, significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test.

Regarding P_{Stem} contents, it was observed that as the ECw levels increased, there was a reduction in the values in plants fertilized with doses equivalent to 60 and 100% of the K_2O recommendation, with decreases of 48.39% (1.64 g kg^{-1}) and 22.44% (0.46 g kg^{-1}), respectively (Figure 4A). On the other hand, when using the dose of 80% of the K_2O recommendation, there was an increase in P_{Stem} content with the increase in ECw of 52.16% (2.03 g kg^{-1}) compared to the lowest water salinity level (0.3 dS m^{-1}). Plants fertilized with potassium doses of 120% of the K_2O recommendation had the highest estimated value (2.98 g kg^{-1}) under ECw of 1.8 dS m^{-1}.

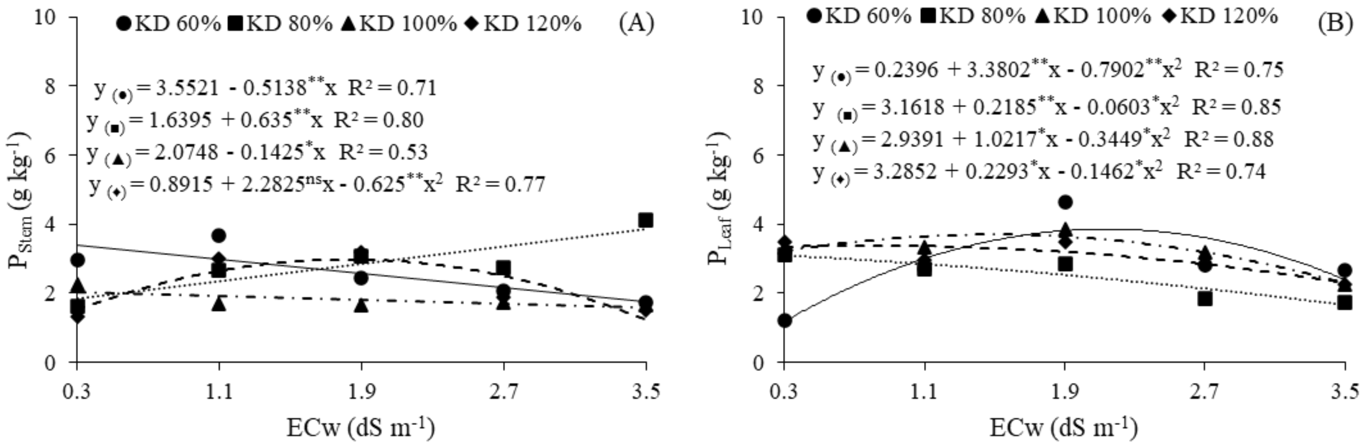


Figure 4. Leaf phosphorus content - P_{Stem} (A) and stem phosphorus content - P_{Leaf} (B) of 'BRS Sol do Cerrado' sour passion fruit plants as a function of the interaction between the levels of electrical conductivity of irrigation water (ECw) and potassium doses (KD) at 160 days after transplanting. ^{ns}, ** and * represent, respectively, non-significant, significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test.

For P_{Leaf} contents, the maximum estimated values of 3.85, 3.48, 3.70 and 3.38 g kg^{-1} were obtained in plants irrigated with ECw of 2.2, 2.4, 1.5 and 0.8 dS m^{-1} and fertilized with doses of 60, 80, 100 and 120% of the K_2O recommendation, respectively (Figure 4B). Malavolta, Vitti and Oliveira (1997) indicate that the adequate range of P in the leaf tissues of passion fruit plants is between 4 and 5 g kg^{-1}, so the results observed in this study are considered insufficient to meet the nutritional requirement of the crop. Lima et al. (2023b) studied the accumulation of nutrients in sour passion fruit plants under salt stress (0.3 and 4.0 dS m^{-1} - varying in the phenological stages) and potassium fertilization (207 and 345 g K_2O per plant) and also found insufficient P content (1.91 to 2.53 g kg^{-1}), in addition to the reduction in P_{Leaf} content with the increase in ECw.

The excess of salts in water and/or soil can cause reduction in the absorption and accumulation of P by plants, due to the effects related to ionic strength, which cause reduction in phosphate activity in the soil solution due to the increase in the concentrations of Na^+ and Cl^- ions in the soil (FREIRE; NASCIMENTO; MEDEIROS, 2020).

The interactions between salinity and mineral nutrition are highly complex processes, influenced by several external factors, such as plant species, genotypes, plant age, ion type and salinity level, nutrient content in the substrate and climatic conditions (FAGERIA; GHEYI; MOREIRA, 2011). Thus, in the present study, the nutrient contents at the end of the first production cycle (160 DAT) varied according to the order of concentration N>Cl>P>Na>K in the leaves, while in the stem the order was N>Cl>P>Na>K, with the increase in the electrical conductivity of irrigation water.

CONCLUSIONS

Increase in the electrical conductivity of irrigation water from 0.3 dS m^{-1} promotes an increase in sodium and chloride contents in leaves and stems of sour passion fruit plants;

Fertilization with a dose of 120% of the K_2O recommendation associated with irrigation with water of up to 1.1 and 1.6 dS m^{-1} increases leaf and stem potassium contents and leaf nitrogen content, respectively, in 'BRS Sol do Cerrado' sour passion fruit plants;

Potassium dose with 60% of the K_2O recommendation promotes an increase in leaf phosphorus content of sour passion fruit plants under irrigation with water of up to 2.2 dS m^{-1};

Irrigation with water of up to 3.5 dS m^{-1} and potassium fertilization with doses of up to 120% of the K_2O recommendation did not significantly influence sulfur accumulation in sour passion fruit plants at 160 days after transplanting.

Nutrient contents in the leaves of sour passion fruit varied according to the order of concentration N>Cl>P>Na>K, while in the stem the order was N>Cl>P>Na>K, with the increase in the electrical conductivity of irrigation water, at 160 DAS.

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