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Potassium fertilization in the cultivation of sour passion fruit under irrigation strategies with brackish water[1]

Adubação potássica no cultivo de maracujazeiro-azedo sob estratégias de irrigação com água salobra

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HIGHLIGHTS:
Potassium dose of 60% of the recommendation promotes greater polar diameter of sour passion fruit.
Regardless of irrigation strategy and K, the pH and titratable acidity of the pulp remain within the ideal range.
Salt stress in the vegetative and vegetative/fruiting stages stimulates the synthesis of flavonoids and anthocyanins.

ABSTRACT: In the Brazilian semiarid region, the occurrence of water sources with high salt concentrations stands out as a limiting factor for the production of most crops under irrigated conditions. This research was conducted to evaluate the physical and chemical quality of sour passion fruit as a function of brackish water irrigation strategies and potassium doses. The experiment was carried out under field conditions using a randomized block design in a 6 × 2 factorial scheme, consisting of six strategies of irrigation with brackish water (irrigation with water of 1.3 dS m^{-1} throughout the cycle – WS; irrigation with water of 4.0 dS m^{-1} in the vegetative stage – VE; flowering stage – FL; fruiting stage – FR; in the successive vegetative/flowering stages – VE/FL; vegetative/fruiting stages – VE/FR) and two potassium doses: 60 and 100% (345 g of K_2O per plant per year) of recommendation, with four replicates and three plants per plot. Irrigation with water of 4.0 dS m^{-1} in the flowering stage or continuously in the vegetative and flowering stages reduced the yield and size of sour passion fruit. Fertilization with 60% of K is recommended for the production of sour passion fruits with greater polar diameter. It is feasible to cultivate sour passion fruit under irrigation with 4.0 dS m^{-1} of water in the flowering and fruiting stages and fertilization with 60% of the K recommendation without losses in ascorbic acid and total soluble sugars.

Key words: *Passiflora edulis*, salt stress, bioactive compounds

RESUMO: No semiárido brasileiro a ocorrência de fontes de águas com níveis elevados de sais se destaca como fator limitante para produção da maioria das culturas sob condições irrigadas. Desenvolveu-se esta pesquisa com o objetivo de avaliar a qualidade física e química de frutos de maracujazeiro-azedo sob estratégias de irrigação com água salobra e doses de potássio. A pesquisa foi desenvolvida em condições de campo, utilizando-se o delineamento de blocos casualizados em esquema fatorial 6 × 2, sendo os tratamentos constituídos de seis estratégias de irrigação com águas salobras (SE - irrigação com água de 1,3 dS m^{-1} durante todo ciclo; irrigação com água de 4,0 dS m^{-1} na fase vegetativa - VE; floração - FL; frutificação - FR; nas fases sucessivas vegetativa/floração - VE/FL; vegetativa/frutificação - VE/FR) e duas doses de potássio 60 e 100% (345 g de K_2O por planta por ano) da recomendação, com quatro repetições e três plantas por parcela. A irrigação com água de 4,0 dS m^{-1} na fase de floração ou quando utilizada de forma contínua na fase vegetativa e de floração reduziu a produtividade e o tamanho dos frutos de maracujazeiro-azedo. Adubação com 60% da recomendação de K proporcionou a produção de frutos de maracujazeiro-azedo com maior diâmetro polar. É viável o cultivo de maracujazeiro-azedo sob irrigação com água de 4,0 dS m^{-1} nas fases de floração e frutificação e adubação com 60% da recomendação de K sem perdas nos teores de ácido ascórbico e açúcares solúveis totais.

Palavras-chave: *Passiflora edulis*, estresse salino, compostos bioativos

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Introduction

Sour passion fruit (*Passiflora edulis*) is a fruit crop of great socioeconomic importance and has stood out mainly among small and medium producers. Its fruits are intended mainly for consumption, either fresh or after processing (Lima et al., 2020a).

Despite the production potential, the Brazilian semiarid region has climatic characteristics, such as high evapotranspiration and low rainfall, which, associated with the scarcity of good quality water, limit the expansion of irrigated fruit crops in this region (Lima et al., 2015; Bezerra et al., 2018; Sá et al., 2018).

The high concentrations of salts present in irrigation water can induce physiological changes that compromise growth, development and the physicochemical quality of fruits (Silva et al., 2019a; Pinheiro et al., 2022). Among the strategies that can reduce the impacts of salt stress, the use of brackish water in the stages in which the crop has greater tolerance (Lima et al., 2020a; Soares et al., 2021) and potassium fertilization (Gurgel et al., 2010) stand out, because the tolerance of plants to salinity may vary between cultivars of the same species, with the phenological stage of the crop and with the duration of the exposure to salts (Silva et al., 2022). Pinheiro et al. (2022), in a study with sour passion fruit under brackish water irrigation strategies varying the phenological stages of the crop, concluded that the passion fruit 'BRS GA1' is sensitive to salt stress in the vegetative and flowering stages continuously.

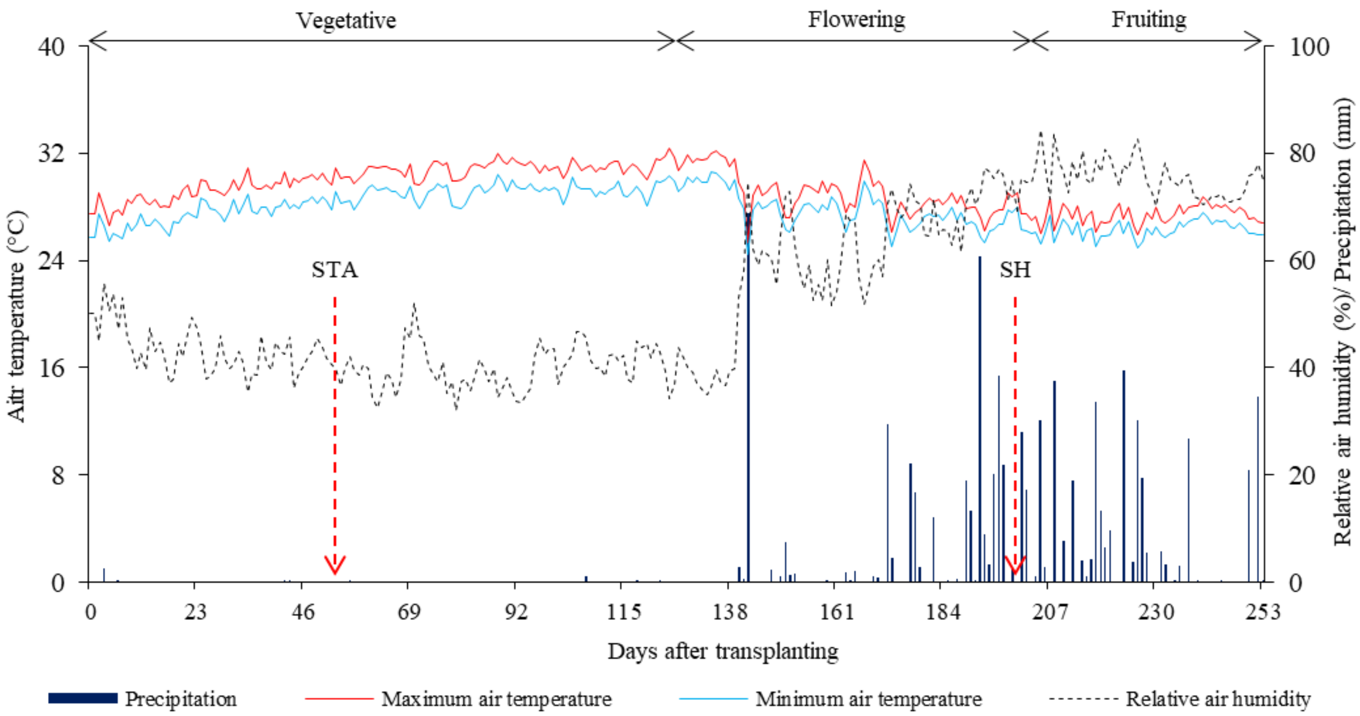
In view of the above, this study was conducted with the objective of evaluating the physical and chemical quality of sour passion fruit as a function of brackish water irrigation strategies and potassium doses.

Material and Methods

The experiment was carried out from August 2019 to May 2020, at the 'Rolando Enrique Rivas Castellón' Experimental Farm, belonging to the Center of Science and Agri-Food Technology - CCTA of the Federal University of Campina Grande - UFCG in Santo Domingos (06° 48' 50" S; 37° 56' 31" W, 190 m and mean altitude of 190 m), Paraíba, Brazil. The data regarding mean maximum and minimum temperatures, precipitation, and relative humidity of air were collected daily at the Meteorological Station São Gonçalo, Sousa - PB and are shown in Figure 1.

The treatments were distributed in randomized blocks in a 6 × 2 factorial scheme, corresponding to six brackish water irrigation strategies – IRS (irrigation with water of 1.3 dS m^{-1} throughout the cultivation cycle - WS; irrigation with water of 4.0 dS m^{-1} in the vegetative stage - VE; flowering stage - FL; fruiting stage - FR; in the successive vegetative/flowering stages - VE/FL; vegetative/fruiting stages - VE/FR) and two potassium doses (60 and 100% of the K_2O recommendation of Costa et al. (2008)), with four replicates, totaling 48 experimental units, each plot consisting of three plants for data collection. The 100% potassium dose corresponded to 345 g of K_2O per plant per year.

The management strategies with electrical conductivity (ECw) of 1.3 dS m^{-1} (low salinity) and 4.0 dS m^{-1} (high salinity) were used in irrigation in the different stages of crop development: irrigation with low-salinity water throughout the cultivation cycle - WS (1-253 days after transplanting - DAT) and with high-salinity water in the stages VE – from the beginning of the emergence of secondary branches to the emergence of the floral primordium (50-113 DAT); FL - from the emergence of the floral primordium to full development



STA – Start of treatment application; SH – Start of the harvest

Figure 1. Data of mean maximum and minimum air temperature, precipitation and relative air humidity during the experimental period

of the floral bud (anthesis) (114-198 DAT); FR - from the fertilization of the floral bud to the appearance of fruits with spots (199-253 DAT); VE/FL - in the vegetative and flowering stages (50-198 DAT); VE/FR - in the vegetative and fruiting stages (50-113 and 199-253 DAT). The ECw values (1.3 and 4.0 dS m^{-1}) of the brackish water irrigation strategies were based on a previous study conducted from November 2018 to July 2019 (Lima et al., 2020a).

Seeds of 'BRS GA1' sour passion fruit were used. It is a genotype with oblong fruits, with a slightly flattened base and apex, weighing from 120 to 350 g, pulp yield around 40% and soluble solids content from 13 to 15 °Brix. It stands out for the homogeneity of the fruit, resistance to transport, bright yellow external color, strong yellow color pulp (higher amount of vitamin C), longer shelf life and good pulp yield, with fruits for industry and table (EMBRAPA, 2008).

During the seedling formation period, irrigation was performed with water of low electrical conductivity (ECw = 1.3 dS m^{-1}). At 61 days after sowing (DAS), transplanting was performed to the area in the field. Brackish water irrigation management started at 50 DAT (Pinheiro et al., 2022).

Tillage practices consisted of plowing followed by harrowing, aiming at breaking up soil clods and leveling the area. The soil of the experimental area was classified as Entisol of loamy sand texture. Before transplanting the seedlings to the field, five soil samples (0-0.40 m layer) were collected at random in the area and later mixed to form a composite sample, whose chemical and physical attributes (Table 1) were determined according to the methodologies described by Teixeira et al. (2017).

After opening the holes of 0.4 × 0.4 × 0.4 m, fertilization with 20 L of bovine manure and 50 g of single superphosphate (18% P_2O_5 and 20% Ca^{2+}) was performed, as recommended by Costa et al. (2008). Nitrogen and potassium fertilizations were performed monthly via fertigation, using urea (45% N) and potassium chloride (60% K_2O) as sources of nitrogen and potassium, respectively; 65 g of N per plant were applied in the crop formation stage and 160 g of N per plant were applied in the flowering and fruiting stages. At the 100% potassium dose, 65 g of K_2O per plant were applied in the vegetative stage and 280 g of K_2O per plant were applied in the flowering and fruiting stages.

Micronutrients were applied fortnightly using a Dripsol® micro compound (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%) at the concentration of 1 g L^{-1}, by foliar spraying on the adaxial and abaxial sides.

The spacing used was 3 m between rows and 3 m between plants, using the vertical trellis system with smooth wire n° 14. Formative pruning, pollination, and other cultural practices and phytosanitary control were carried out as described by Pinheiro et al. (2022).

The irrigation water with electrical conductivity of 1.3 dS m^{-1} came from an artesian well located in the experimental area of CCTA/UFCG, whose chemical composition is presented in Table 2. The water with ECw of 4.0 dS m^{-1} was prepared by dissolving iodine-free NaCl in well water. The irrigation water with the highest salinity level was prepared considering the relationship between ECw and the concentration of salts (Richards, 1954), according to Eq. 1:

$$C \cong 640 \times ECw \tag{1}$$

where:

C - concentration of salts in irrigation water (mg L^{-1}); and,
ECw - Electrical conductivity of water (dS m^{-1}).

After dissolving the NaCl to obtain an ECw level of 4.0 dS m^{-1}, electrical conductivity of water was verified with the help of a conductivity meter at 25 °C temperature and corrected, if necessary.

Irrigation was applied by a localized drip system, using 32-mm-diameter PVC pipes in the main line and 16-mm-diameter low-density polyethylene pipes in the lateral lines, with drippers with flow rate of 10 L h^{-1}. Two pressure-compensating drippers (GA 10 Grapa model) were installed close to each plant, each 15 cm away from the stem. Plants were irrigated daily at 07:00 a.m., with water according to the strategy adopted, and the depth to be applied was estimated based on crop evapotranspiration, according to a study conducted by Pinheiro et al. (2022).

Reference evapotranspiration (ET_0) was determined daily from climatic data collected at the São Gonçalo Meteorological

Table 1. Chemical and physical attributes of the soil (0-40 cm layer) of the experimental area

Chemical attributes								
pH H_2O (1:2.5)	OM (dag kg^{-1})	P (mg kg^{-1})	K^+ (cmol$_c$ kg^{-1})	Na^+ (cmol$_c$ kg^{-1})	Ca^{2+} (cmol$_c$ kg^{-1})	Mg^{2+} (cmol$_c$ kg^{-1})	Al^{3+} (cmol$_c$ kg^{-1})	H^+ (cmol$_c$ kg^{-1})
7.82	0.81	10.60	0.30	0.81	2.44	1.81	0.00	0.00

Chemical characteristics				Physical attributes				
				Particle-size fraction (g kg^{-1})			Moisture (dag kg^{-1})	
EC_{se} (dS m^{-1})	CEC (cmol$_c$ kg^{-1})	SAR_{se} (mmol L^{-1})$^{0.5}$	ESP (%)	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; EC_{se} - 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, respectively

Table 2. Chemical attributes of the well water used in the experiment

Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	CO_3^{2-}	Cl^-	EC	pH	SAR
(mmol$_c$ L^{-1})							(dS m^{-1})		(mmol$_c$ L^{-1})$^{0.5}$
0.85	0.40	5.81	0.40	5.09	0.00	4.07	1.30	6.69	7.34

EC - Electrical conductivity; SAR - Sodium adsorption ratio

Station, located in the municipality of Sousa - PB, and the data were used to determine ET_0 by the Penman-Monteith method. Crop coefficients of 0.4 (1-113 DAT), 0.8 (114-198 DAT) and 1.2 (199-253 DAT) were adopted, according to the recommendation of Nunes et al. (2017).

During the experimental period, the cultural practices and phytosanitary treatments recommended for the crop were carried out, controlling weeds, monitoring the appearance of pests and diseases, and adopting adequate control measures when necessary.

The harvest was conducted between 199 and 253 DAT. The fruits were collected by individually removing the plant, cutting the peduncle when the fruit color changed from green to partially yellow, and before detaching from the mother plant (Costa et al., 2008). After harvesting, the fruits were packed in boxes and separated by paper, which also covered the boxes, to avoid friction and mechanical damage to them.

To determine the postharvest quality, the fruits were washed in chlorinated water to remove impurities or residues of agricultural pesticides. The physical characterization of the fruits was carried out through the equatorial (DE) and polar (DP) diameters, with the determinations made in 20 fruits per plant. The DE was measured in the median region in the width direction and the DP in the direction from the base to the apex of the fruit, using a digital Vernier caliper.

After pulping, the fruit-pulp was evaluated for concentrations of flavonoids (FLA), anthocyanins (ANT), soluble solids (SS), total soluble sugars (TSSg), ascorbic acid (AA), titratable acidity (TA), and hydrogen potential (pH). Concentrations of anthocyanin and flavonoids, and soluble solids (refractometry) were determined according to the methodology proposed by Adolfo Lutz Institute (IAL, 2008). Soluble sugars were measured using the colorimetric method (Somogyi, 1952). Ascorbic acid concentration was determined by the titration method until the solution acquired a blue color, and the results were expressed as mg vit. C $100g^{-1}$). Titratable acidity was determined in triplicate and the results obtained were converted into a percentage of citric acid, according to the methodology of IAL (2008). Hydrogen potential was determined directly using a digital pH meter previously calibrated with buffer solutions of pH 7.0 and 4.0.

The obtained data were evaluated by analysis of variance, after data normality and homogeneity test (Shapiro-Wilk test). Tukey test at $p \leq 0.05$ was applied for brackish water irrigation strategies and potassium doses, using the statistical program SISVAR (Ferreira, 2019).

Results and Discussion

According to the summary of the analysis of variance (Table 3), brackish water irrigation strategies significantly affected the equatorial diameter (ED) and polar diameter (PD), concentrations of flavonoids (FLA) and anthocyanin (ANT), and hydrogen potential (pH). Except for equatorial diameter, potassium doses significantly influenced all variables analyzed. The interaction between the factors (IRS × KD) significantly affected the FLA and ANT concentrations and pH of 'BRS GA1' sour passion fruit.

Table 3. Summary of the analysis of variance for equatorial diameter (ED), polar diameter (PD), flavonoids (FLA), anthocyanins (ANT), and hydrogen potential (pH) of 'BRS GA1' sour passion fruit cultivated under different brackish water irrigation strategies and potassium fertilization

Source of variation	DF	Mean squares				
		ED	PD	FLA	ANT	pH
Irrigation strategy (IRS)	5	360.43^{*}	328.78^{*}	0.18^{**}	0.0008^{**}	0.03^{**}
Potassium doses (KD)	1	177.71^{ns}	555.69^{*}	0.14^{**}	0.005^{**}	0.005^{*}
Interaction (IRS × KD)	5	87.91^{ns}	103.59^{ns}	0.36^{**}	0.001^{**}	0.03^{**}
Blocks	3	150.03^{ns}	88.85^{ns}	0.004^{ns}	0.000008^{ns}	0.0002^{ns}
Residual	33	79.28	93.31^{ns}	0.003	0.000006^{ns}	0.0009
CV (%)		10.81	10.66	9.60	7.47	1.05

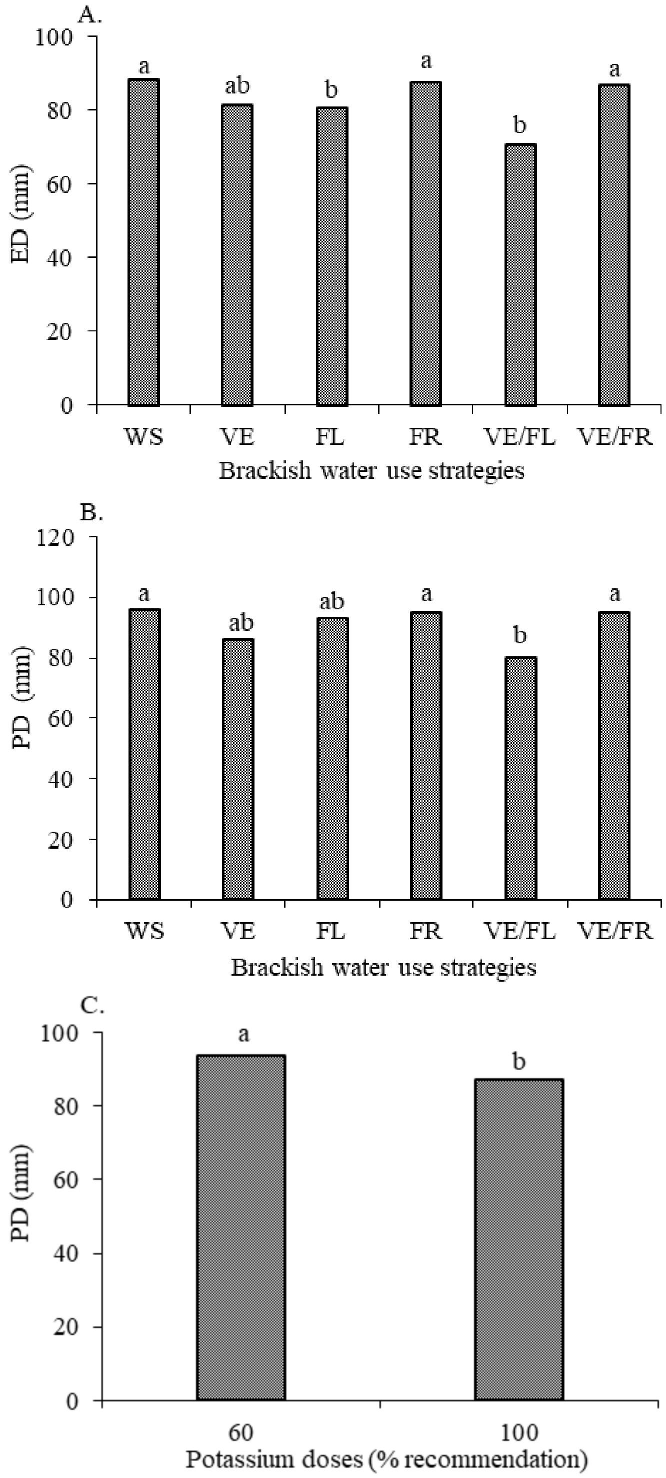
DF - Degrees of freedom; CV (%) - Coefficient of variation; * - Significant at $p \leq 0.05$ by F test; ** - Significant at $p \leq 0.01$ by F test; ns - Not significant

The equatorial diameters of the fruits (Figure 2A) of plants subjected to the irrigation strategy with low-salinity water throughout the cultivation cycle (WS), fruiting (FR), and vegetative and fruiting stages (VE/FR) were statistically higher than those of plants that received the high salinity of ECw = 4.0 dS m^{-1} in the flowering stage or continuously in the vegetative and flowering stages. A comparison between plants that received irrigation with ECw of 4.0 dS m^{-1} in the vegetative, flowering and vegetative/flowering stages showed that there were no significant differences among them. The reduction in fruit size is a consequence of energy expenditure for the maintenance of metabolic activities, i.e., the maintenance of ionic and osmotic homeostasis, through the accumulation of sugars, organic acids, and ions in the vacuole (Lima et al., 2020b; Lacerda et al., 2022).

Another factor that may have contributed to the decrease in fruit diameters was the period of stress to which the plants were subjected, considering that in the vegetative stage there was no contribution from precipitation, and in the flowering stage, rains started from 138 DAT and were poorly distributed throughout the cycle. It is important to highlight that in the VE/FL stages the precipitations were concentrated over 26 days. Dias et al. (2021), when evaluating the production of West Indian cherry cv. BRS 366 Jaburu under irrigation with saline water and potassium-phosphorus fertilization in two production cycles, in the second year of cultivation, found that ECw from 0.6 dS m^{-1} led to a decrease in polar diameter of fruit.

The polar diameter of sour passion fruit was also significantly influenced by the brackish water irrigation strategies (Figure 2B). Plants grown under the strategies WS, FR and VE/FR stood out with the highest PD compared to those subjected to salt stress in the vegetative/flowering stages. However, when comparing the PD values of plants under the strategies WS, VE, FL, FR and VE/FR, there were no significant differences among them. Irrigation with high-salinity water (4.0 dS m^{-1}) continuously in the vegetative and flowering stages was harmful to fruit formation. Salt stress compromises reproductive processes in plants, due to the possible accumulation of toxic ions (Na^{+} and/or Cl^{-}), and reduces the supply of assimilates to reproductive tissues due to decreases in leaf area and water restriction and/or hormonal imbalances (Khan et al., 2017).

Regarding the effects of potassium doses on the polar diameter of sour passion fruit (Figure 2C), plants subjected to fertilization with 60% of the recommendation of



Bars with different letters indicate significant difference among treatments by Tukey test ($p \leq 0.05$); WS - Irrigation with low-salinity water throughout the cultivation cycle (1-253 days after transplanting - DAT); salt stress in VE - Vegetative stage (50-113 DAT); FL - Flowering stage (114-198 DAT); FR - Fruiting stage (199-253 DAT); VE and FL - Vegetative and flowering stages (50-198 DAT); VE/FR - Vegetative and fruiting stages (50-113 and 199-253 DAT)

Figure 2. Equatorial diameter - ED (A) and polar diameter - PD (B) of 'BRS GA1' sour passion fruit as a function of the different brackish water irrigation strategies and PD as a function of potassium doses (C)

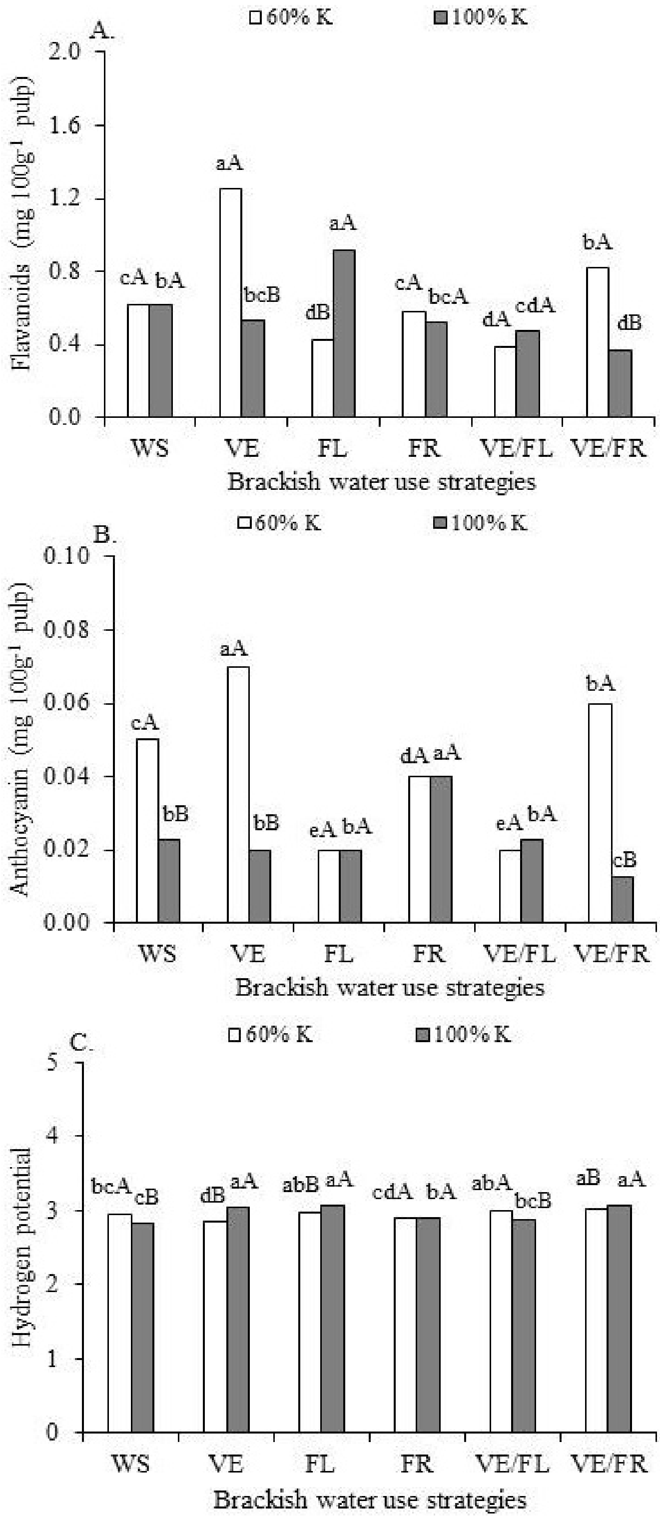
Costa et al. (2008) obtained a higher PD compared to the values of those that were under 100% K recommendation. In relative terms, plants fertilized with 100% K had a reduction of 6.81 mm (7.24%) in PD compared to those that received 60% of the recommendation. It is noteworthy that, at the time of fertilization, potassium levels in the soil were not considered adequate for the sour passion fruit crop, being classified as low (Table 1). Despite the low levels of K in the soil, under the edaphoclimatic conditions of the semiarid region of Northeast Brazil, the dose of 100% of K (Costa et al., 2008) may have been excessive for the crop. Another aspect that may have led to a decrease in fruit size was the K source used in the present study, since potassium chloride has a high salt index (116) and may have caused a reduction in the levels of Ca^{2+} and Mg^{2+} in plants, due to the existence of competition between these cations (Dias et al., 2021).

For the flavonoid concentrations - FLA (Figure 3A) of sour passion fruit, plants fertilized with a dose of 60% of the K recommendation obtained the highest value (1.25 mg $100g^{-1}$ pulp) when they were subjected to irrigation with water with the highest level of electrical conductivity (4.0 dS m^{-1}) in the vegetative stage, being statistically superior to those under the other irrigation strategies (WS, FL, VE/FL, FR, VE/FR). Plants grown under fertilization with 100% of the recommendation of Costa et al. (2008) stood out with the highest FLA when they were irrigated with water of 4.0 dS m^{-1} in the flowering stage, differing significantly from plants irrigated with low-ECw water (WS) along the crop cycle and subjected to salt stress in the vegetative, fruiting, vegetative/flowering and vegetative/fruiting stages. When comparing the FLA concentrations between the K doses, the best results were obtained when plants received 60% of K in the vegetative and vegetative/fruiting stages and 100% in the flowering stage (Figure 3A).

The antioxidant activity of phenolic compounds is mainly due to their reducing properties and chemical structure (Silva et al., 2019b), characteristics that play an important role for them to be recognized as antioxidant agents, due to their action as singlet oxygen reducers, acting on lipid oxidation reactions, as well as on metal chelation (Dastmalchi et al., 2008). Thus, the increase in flavonoid concentrations obtained in plants under salt stress in the VE and FL stages may have occurred because flavonoids are phenolic compounds that have antioxidant properties and their function in plants is related to stress response, since flavonoids can mitigate oxidative damage caused by salt stress conditions.

The anthocyanin concentrations in sour passion fruit were also influenced by the interaction between the factors - IRS × KD (Figure 3B). Plants fertilized with 60% of the K recommendation stood out with the highest ANT concentrations when they were irrigated with water of 4.0 dS m^{-1} in the vegetative stage, being statistically superior to those that received the strategies WS, FL, FR, VE/FL and VE/FR. Plants grown under fertilization with 100% K obtained the highest ANT concentrations when they received water of 4.0 dS m^{-1} in the fruiting stage. When comparing the effects between doses, higher ANT concentrations were found in plants grown under 60% K doses in the strategies WS, VE and VE/FR.

Anthocyanins are pigments that have antioxidant capacity, defense mechanism and biological function, and their production may have been induced in the fruits of plants subjected to stress in the VE and VE/FR stages as a form of protection, since the synthesis of anthocyanins is induced by stress due to oxidation, because changes in metabolism due to



Bars with the same uppercase letters indicate no significant differences between potassium doses in the same brackish water irrigation strategy, and bars with the same lowercase letters for the same potassium dose indicate no significant differences between the brackish water irrigation strategies (Tukey test, $p \leq 0.05$); WS - Irrigation with low-salinity water throughout the cultivation cycle (1-253 days after transplanting - DAT); salt stress in VE - Vegetative stage (50-113 DAT); FL - Flowering stage (114-198 DAT); FR - Fruiting stage (199-253 DAT); VE/FL - Vegetative and flowering stages (50-198 DAT); VE/FR - Vegetative and fruiting stages (50-113/199-253 DAT)

Figure 3. Flavonoids - FLA (A), anthocyanins - ANT (B) and hydrogen potential (C) of 'BRS GA1' sour passion fruit pulp as a function of the interaction between brackish water irrigation strategies and potassium doses

the accumulation of ions (Na^+ and Cl^-) in plant tissues lead to an excessive production of reactive oxygen species, which can cause oxidative stress in plants (Parvaiz & Satyawati, 2008).

The hydrogen potential (pH) in the pulp (Figure 3C) from sour passion fruit plants subjected to fertilization with 100% K and irrigation with water of 4.0 dS m^{-1} in the VE, FL and VE/FR stages was higher than those that received 60% K. However, plants subjected to salt stress in the VE/FL stages and without stress (WS) fertilized with 60% K had higher pH than those which received 100% of the recommendation. It is worth pointing out that the pH values obtained, regardless of the irrigation strategy and potassium dose, are within the ideal range recommended by the Ministry of Agriculture, Livestock and Food Supply for quality of passion fruit pulps, because a pH lower than 4.5 is desirable to prevent the proliferation of microorganisms and pH values higher than 4.5 require longer periods of sterilization of the raw material in a thermal processing, resulting in higher energy consumption and higher processing cost (Monteiro et al., 2008; Lima et al., 2020b). Lima et al. (2020b), when evaluating the effects of irrigation with water of increasing salinity on the physicochemical composition of fresh fruits of 'BRS 366 Jaburu' West Indian cherry, observed a decrease in pH of 3.02% per unit increment in ECw.

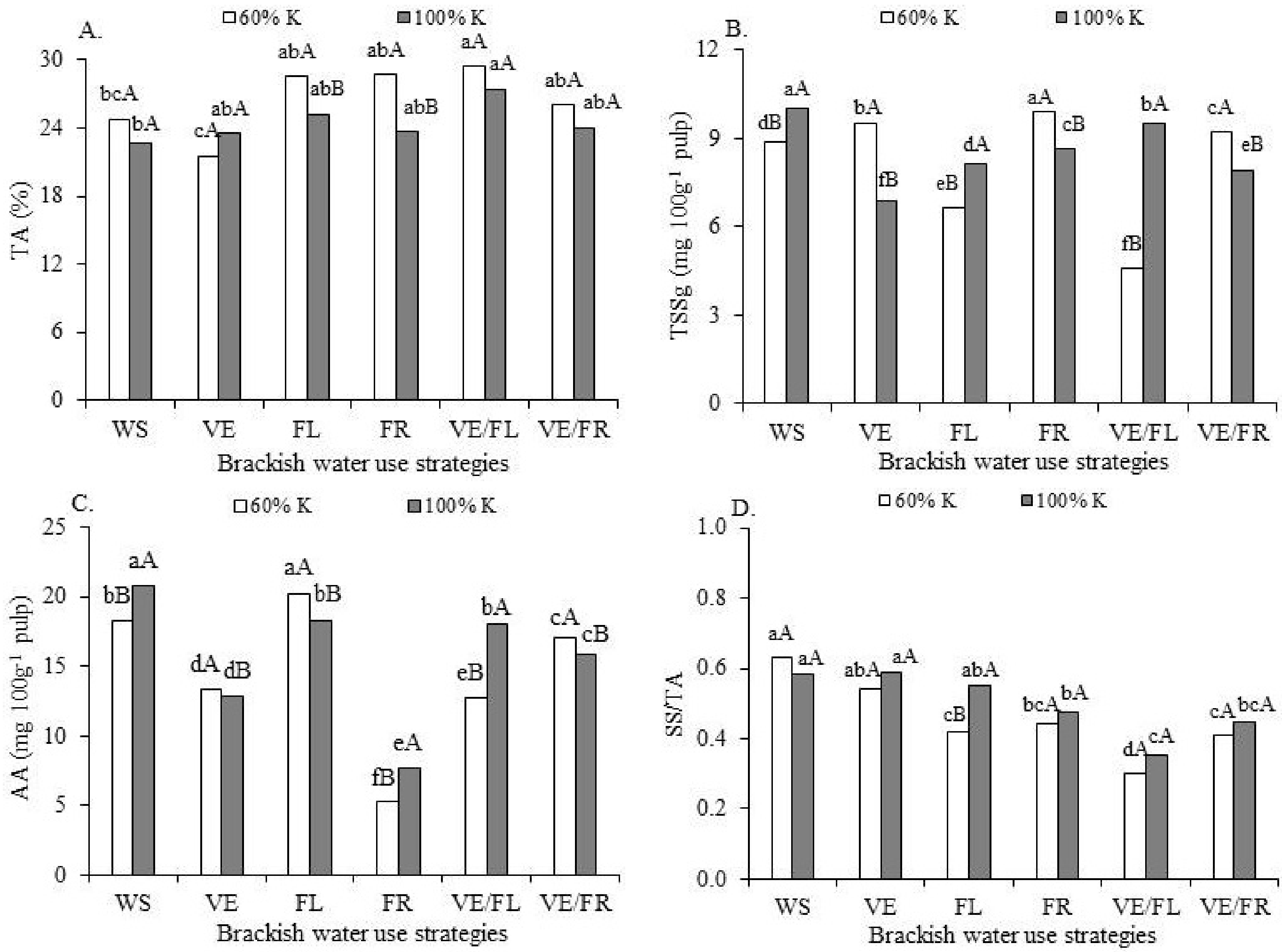
There was significant effect of the brackish water irrigation strategies on titratable acidity (TA), total soluble sugars (TSSg), ascorbic acid (AA), and soluble solids/ titratable acidity ratio (SS/TA) of 'BRS GA1' sour passion fruit, at 253 days after transplanting (Table 4). Potassium doses significantly influenced TA, TSSg, AA, and SS/TA. The interaction between the factors (IRS × KD) significantly affected the titratable acidity, total soluble sugars, and the ascorbic acid concentrations of 'BRS GA1' sour passion fruit.

For the titratable acidity (Figure 4A) of the sour passion fruit pulp, plants fertilized with 60% K and subjected to high-salinity water in the stages VE/FL stood out with the highest value, differing statistically from those grown under the strategies WS and VE. For plants grown under fertilization with 100% of the K recommendation, there were no significant differences between the brackish water irrigation strategies, except for VE/FL and WS. When comparing TA as a function of K doses, better results were obtained in plants fertilized with 60% compared to those that received 100% in the flowering (FL) and fruiting (FR) stages. For the other irrigation strategies, there were no significant differences between them. It is worth pointing out that in all treatments evaluated, the TA levels exceeded the minimum value established for passion fruit pulp,

Table 4. Summary of the analysis of variance for soluble solids (SS), titratable acidity (TA), total soluble sugars (TSSg), ascorbic acid (AA), and soluble solids/titratable acidity ratio (SS/TA) of pulp of 'BRS GA1' sour passion fruit cultivated under different brackish water irrigation strategies and potassium fertilization

Source of variation	DF	Mean squares				
		SS[1]	TA	TSSg	AA	SS/TA
Irrigation strategy (IRS)	5	153.22^{ns}	37.46**	7.69**	188.00**	0.07**
Potassium doses (KD)	1	81.38^{ns}	52.96*	1.97**	14.55**	0.01*
Interaction (IRS × KD)	5	125.88^{ns}	10.92*	14.88**	15.15**	0.006^{ns}
Blocks	3	173.17^{ns}	1.27^{ns}	0.0006^{ns}	0.16^{ns}	0.0005^{ns}
Residual	33	169.17^{ns}	3.49	0.0011	0.05	0.002
CV (%)		25.68	7.35	0.41	1.63	10.57

DF - Degrees of freedom; CV (%) - Coefficient of variation; * - Significant at $p \leq 0.05$ by F test; ** - Significant at $p \leq 0.01$ by F test; ^{ns} - Not significant; [1] Data transformed into $\sqrt{x}$



Bars with the same uppercase letters indicate no significant differences between potassium doses in the same brackish water irrigation strategy, and bars with the same lowercase letters for the same potassium dose indicate no significant differences between the brackish water irrigation strategies (Tukey test, $p \leq 0.05$); WS - Irrigation with low-salinity water throughout the cultivation cycle (1-253 days after transplanting - DAT); salt stress in VE - Vegetative stage (50-113 DAT); FL - Flowering stage (114-198 DAT); FR - Fruiting stage (199-253 DAT); VE/FL - Vegetative and flowering stages (50-198 DAT); VE/FR - Vegetative and fruiting stages (50-113/199-253 DAT)

Figure 4. Titratable acidity - TA (A), total soluble sugars - TSSg (B), ascorbic acid - AA (C), and soluble solids/titratable acidity - SS/TA (D) of 'BRS GA1' sour passion fruit pulp as a function of the interaction between brackish water irrigation strategies and potassium doses

which is 2.5% (Brasil, 2018). These results are in agreement with those presented by Lima et al. (2020b), who also found an increase in the TA of West Indian cherry subjected to irrigation with water of 3.8 dS m^{-1}. According to these authors, the increase in TA is related to changes in the metabolic and physiological processes of plants caused by salt stress, which increases the synthesis of organic acids such as citric and malic.

As for the concentrations of total soluble sugars in sour passion fruit (Figure 4B), plants subjected to fertilization with 60% K and irrigated with water of 4.0 dS m^{-1} in the fruiting (FR) stage obtained the highest values. Conversely, the lowest TSSg concentrations were verified in plants that received water of 4.0 dS m^{-1} in the vegetative and flowering (VE/FL) stages continuously. For plants fertilized with 100% K, higher TSSg concentrations were obtained with the strategies WS and VE/FL. When analyzing the effects of K doses considering each irrigation strategy, it was observed that fertilization with 60% K resulted in higher TSSg concentrations in plants subjected to salt stress in the VE, FR, and VE/FR stages. For plants fertilized with 100% K, higher TSSg concentrations were obtained under the strategies WS, FL, and VE/FL.

The increase in the concentrations of total soluble sugars (TSSg) in plants subjected to salt stress in the VE, FR, and VE/FR stages and fertilization with 60% K recommendation (Figure 4B) occurs due to the reduction of the plant's capacity to absorb soil water, compromising the transport via phloem and, consequently, generating a dilution effect of these sugars (Simões et al., 2019). Lacerda et al. (2021), when evaluating the fruit quality of West Indian cherry cv. Flor Branca, subjected to irrigation with water of different salinity levels (ECw: 0.3 to 4.3 dS m^{-1}) and nitrogen-potassium fertilization combinations, between 630 and 750 DAT, observed that ECw of 3.3 dS m^{-1} increased the concentrations of total soluble sugars.

Regarding the ascorbic acid concentrations (Figure 4C), in plants fertilized with 60% K recommendation, the highest concentration (20.24 mg $100g^{-1}$ pulp) was obtained in plants irrigated with water of 4.0 dS m^{-1} in the flowering stage, significantly differing from the other brackish water irrigation strategies (WS, VE, FR, VE/FL, and VE/FR). However, irrigation with high-salinity water in the fruiting stage resulted in the lowest AA concentration (5.25 mg $100g^{-1}$ pulp). Plants grown under fertilization with 100% of the K recommendation obtained the highest AA concentration when they received water of 1.3 dS m^{-1} throughout the cultivation cycle. At this dose, the lowest AA concentration (7.67 mg $100g^{-1}$ pulp) was also observed in the fruiting stage.

When comparing the effect of K doses considering each irrigation strategy, higher AA concentrations were found in plants fertilized with 60% K, in the stages of VE, FL, and VE/FR compared to those that received 100% K. Conversely, plants that received 100% K obtained the highest AA concentrations when subjected to the strategies WS, FR, and VE/FL compared to those fertilized with 60% K. The AA concentrations obtained in this study are higher than those found by Dias et al. (2011), who studied the post-harvest quality of yellow passion fruit under irrigation with saline water (ECw ranging from 0.5 to 4.5 dS m^{-1}) and observed a linear decrease in AA levels with the increase in ECw levels.

The decrease in ascorbic acid concentrations may be related to changes in the translocation of photoassimilates due to the stress caused by excess salts in irrigation water (Lima et al., 2020b), as previously mentioned for TSSg. Dias et al. (2011) also found that irrigation with water of 4.5 dS m^{-1} reduced the concentrations of vitamin C (ascorbic acid) in sour passion fruit and stated that the decrease of this compound is a consequence of the reduction in the synthesis of hexose sugars, originally D-glucose or D-galactose.

As for the SS/TA ratio (Figure 4D), fruits from plants fertilized with 60% K and subjected to the strategies WS and VE obtained a statistically higher SS/TA ratio compared to those from plants that received salt stress in the FL, VE/FL, and VE/FR stages. When the 100% K dose was used, the highest SS/TA ratios were obtained with the strategies WS, VE, and FL. The lowest value of SS/TA ratio was obtained in plants cultivated with high-salinity water (4.0 dS m^{-1}) in the vegetative (VE) and flowering (FL) stages continuously. When analyzing the effect of K doses considering each irrigation strategy, there was a significant difference between plants fertilized with 60 and 100% K only in the strategy FL, with higher SS/TA ratio obtained with 100% of the K recommendation. SS/TA ratio is an important parameter used in the evaluation of fruit flavor because it indicates the balance between acidity and sugars.

From the results obtained in this study it can be inferred that the 100% K dose and irrigation using water with electrical conductivity of 4.0 dS m^{-1} in the flowering stage increased the SS/TA ratio, standing out as an alternative for passion fruit cultivation. This fact is due to the positive effect of K on the activation of enzymes involved in photosynthesis, maintenance of ionic balance, cell turgor, starch synthesis, and transport of carbohydrates, via phloem, indispensable for fruit formation (Hasanuzzaman et al., 2018).

Conclusions

1. Irrigation with water of 4.0 dS m^{-1} in the flowering stage or continuously in the vegetative and flowering stages reduces the size of sour passion fruit.

2. Fertilization with 60% of K recommendation (207g K_2O per plant per year) increases the sour passion fruit polar diameter.

3. The highest concentrations of flavonoids and anthocyanins in sour passion fruit are obtained with 60% of K recommendation and irrigation with water of 4.0 dS m^{-1} in the vegetative stage.

4. It is feasible to cultivate sour passion fruit under irrigation with water of 4.0 dS m^{-1} in the flowering and fruiting stages and fertilization with 60% of the K recommendation without losses in ascorbic acid and total soluble sugars.

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