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Growth, photosynthetic pigments, and photochemical efficiency of sour passion fruit as a function of the cationic nature of water

Crescimento, pigmentos fotossintéticos e eficiência fotoquimica do maracujazeiro-azedo em função da natureza catiônica da água

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Highlights

Passion fruit growth is affected by salt stress, regardless of the cationic nature of water.
The use of water with sodium favors the synthesis of photosynthetic pigments.
The cationic nature of water does not influence the fluorescence of passion fruit.

Abstract

The objective of this study was to evaluate the growth, photosynthetic pigments, and photochemical efficiency of sour passion fruit cv. BRS Rubi do Cerrado irrigated with waters of different cationic natures. The experiment was carried out from March 2019 to January 2020 in a protected environment belonging to the Academic Unit of Agricultural Engineering of the Federal University of Campina Grande (UFCG), Campina Grande, PB, Brazil. The treatments consisted of eight combinations of irrigation water with different cationic natures: S_1 - Control; S_2 - Na+; S_3 - Ca^{2+}; S_4 - Mg^{2+}; S_5 - $Na^{\pm}$ + Ca^{2+}; S_6 - Na^{+} + Mg^{2+}; S_7 - Ca^{2+} + Mg^{2+}, and S_8 - Na^{+} + Ca^{2+} + Mg^{2+}. Plants in the control treatment (S_1) were irrigated using water with an electrical conductivity (ECw) of 0.4 dS m^{-1}, while the other treatments (S_2; S_3; S_4; S_5; S_6; S_7; and S_8) were subjected to an ECw of 3.5 dS m^{-1}. Sour passion fruit growth was affected by variations in the level of electrical conductivity, regardless of the cationic nature of irrigation water. The use of salinized water with sodium favored the synthesis of chlorophyll a, chlorophyll b, and carotenoids of passion fruit plants at 180 days after transplanting. The distinct cationic natures of irrigation water did not influence the fluorescence variables of sour passion fruit.
Key words: *Passiflora edulis.* Semi-arid region. Water scarcity. Salinity.

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Resumo

Objetivou-se com o presente estudo avaliar o crescimento, os pigmentos fotossintéticos, a eficiência fotoquímica do maracujazeiro-azedo cv. BRS Rubi do Cerrado irrigado com águas de distintas naturezas catiônicas. O experimento foi realizado no período de março de 2019 a janeiro de 2020 em ambiente protegido pertencente a Unidade Acadêmica de Engenharia Agrícola da Universidade Federal de Campina Grande (UFCG), Campina Grande, PB. Os tratamentos foram constituídos de oito combinações de água de irrigação de diferentes naturezas catiônicas: S_1 - Testemunha; S_2 - Na^+; S_3 - Ca^{2+}; S_4 - Mg^{2+}; S_5 - Na^+ + Ca^{2+}; S_6 - Na^+ + Mg^{2+}; S_7 - Ca^{2+} + Mg^{2+} e S_8 - Na^+ + Ca^{2+} + Mg^{2+}. As plantas do tratamento testemunha (S_1) foram irrigadas com água de condutividade elétrica (CEa) de 0,4 dS m^{-1}, já nos demais tratamentos (S_2; S_3; S_4; S_5; S_6; S_7 e S_8) utilizou-se CEa de 3,5 dS m^{-1}. O crescimento do maracujazeiro-azedo foi afetado pela variação no nível da condutividade elétrica da água, independentemente da natureza catiônica da água de irrigação. O uso de água salinizada com sódio favoreceu na síntese de clorofila a, b e carotenóides das plantas de maracujazeiro-azedo, aos 180 dias após o transplantio. As distintas naturezas catiônicas da água de irrigação, não influenciaram nas variáveis de fluorescência do maracujazeiro-azedo.
Palavras-chave: *Passiflora edulis.* Semiárido. Escassez hidrica. Salinidade.

Introduction

Sour passion fruit (*Passiflora edulis*) belongs to the Passifloraceae family, which is composed of about 520 species but few are considered economically important (Ferreira et al., 2019). Brazil stands out as the largest producer and exporter of this fruit, having produced 602,651 Mg in 2018, with an average national production of 13.93 Mg ha^{-1} $year^{-1}$ (Instituto Brasileiro de Geografia e Estatística [IBGE], 2019).

The great economic importance of sour passion fruit is due to the full use of its fruit; the pulp is used for fresh consumption or in the manufacture of various by-products, the rind is used as feed for animals, and the seeds are used to extract oils destined for the cosmetics and pharmaceutical industry. However, passion fruit quality is influenced by factors related to cultivars, climate, soil, and cultural practices, including fertilization and irrigation (Rocha et al., 2013).

Among the limitations for the production of sour passion fruit in the semi-arid region of Northeastern Brazil is the unavailability of water for irrigation, due to the spatial-temporal irregularity of rainfall characteristics in this region (E. N. Silva, Ribeiro, Ferreira-Silva, Viégas, & Silveira, 2011). Consequently, farmers often choose to drill wells to use as the main source of water for irrigation but in general, these waters have restrictions for use, mainly because of the hydrogeological conditions favorable to high salt levels (N. S. Santos et al., 2020). In addition, the soils of this region are generally characterized by large amounts of salts, which significantly compromise agricultural activities in these areas (Holanda, Amorim, Ferreira Neto, Holanda, & Sá, 2016).

The main salts present in water and soil in the semi-arid region are sodium chloride (NaCl), calcium chloride ($CaCl_2$), magnesium sulfate ($MgSO_4$), sodium sulfate (Na_2SO_4), magnesium chloride ($MgCl_2$), and sodium carbonate (Na_2CO_3) (Kovda, Yaron, & Shalhevet, 1973). The commonly found proportion of cations present in the water sources of the semi-arid region is 7:2:1 among sodium, calcium, and magnesium, respectively (A. S. Dias, Lima, Gheyi, Nobre, & Santos, 2017). Among the abiotic stresses, salinity is the one that most affects crop development. Excess salts cause a reduction in the osmotic potential of the soil, limiting the absorption of water and nutrients, negatively interfering in the biochemical and physiological processes of plants (Cruz, Coelho, Coelho, & Santos, 2018).

In this scenario, several studies have been carried out with the objective of analyzing the deleterious effects of salinity on several aspects of the passion fruit crop (Souza et al., 2018; J. R. Andrade, Medeiros, Maia, Rezende, & Araújo, 2018; Moura et al., 2019; E. M. G. Andrade, Lima, Lima, Gheyi, & Silva, 2019; Lima et al., 2020). However, these studies are limited to the evaluation of only different salinity levels, so it is extremely important to conduct research on the effects of the different cationic compositions of water, especially for sour passion fruit cv. 'BRS Rubi do Cerrado' to adopt an appropriate management plan for crop production.

In this context, the aim of this study was to evaluate the photosynthetic pigments, photochemical efficiency, and growth of sour passion fruit cv. BRS Rubi do Cerrado irrigated with waters of different cationic natures.

Materials and Methods

The experiment was carried out from March 2019 to January 2020 in a protected environment belonging to the Academic Unit of Agricultural Engineering of the Federal University of Campina Grande (UFCG), campus of Campina Grande, PB, Brazil, located at local geographic coordinates 7° 15′ 18″ S, and 35° 52′ 28″ W and an altitude of 550 m.

The treatments consisted of eight combinations of irrigation water with different cationic natures: S_1 - Control; S_2 - Na^+; S_3 - Ca_2+; S_4 - Mg^{2+}; S_5 - $Na^+ + Ca^{2+}$; S_6 - $Na^+ + Mg^{2+}$; S_7 - $Ca^{2+} + Mg^{2+}$, and S_8 - $Na^+ + Ca_2$+ + Mg^{2+}. Plants in the control treatment (S_1) were irrigated using water with an electrical conductivity (ECw) of 0.4 dS m^{-1}, while the other treatments (S_2; S_3; S_4; S_5; S_6; S_7; and S_8) were subjected to an ECw of 3.5 dS m^{-1}. The treatments Na^+ + Ca_2+, $Na^+ + Mg^{2+}$, and $Ca^{2+} + Mg^{2+}$ were prepared in such a way to have an equivalent proportion of 1:1 and the treatment $Na^+ + Ca^{2+} + Mg^{2+}$, an equivalent proportion of 7:2:1, respectively. The experimental design was randomized blocks, consisting of eight treatments and three replicates, totaling 24 experimental plots.

The lysimeters were filled with 240 kg of soil, leaving a 10-cm-high free space at the top of the lysimeter to facilitate irrigation. Prior to transplanting, the volume of water required for the soil to reach field capacity was verified through the soil water balance method (drainage lysimetry). The soil used in the experiment was collected at 0–30 cm depth (A horizon), with sandy clay loam texture, from the municipality of Alagoa Nova, PB, and its physical and chemical attributes were obtained according to the methodology proposed by Donagema, Campos, Calderano, Teixeira and Viana (2011). These attributes showed the following: Ca^{2+}, Mg^{2+}, Na^+, K^+, $Al^{3+} + H^+$ = 1.67, 1.56, 0.04, 79.30, 7.21 $cmol_c$ kg^{-1}, respectively; pH (water 1:2.5) = 5.3; ECse = 0.41 dS m^{-1}; organic matter = 2.863 dag kg^{-1}; sand, silt and clay = 68.8, 9.6 and 21.6 dag kg^{-1}, respectively; bulk density (kg dm^{-3}) = 1.16.

The seedlings were grown in polyethylene bags with a volumetric capacity of 1.5 kg filled with substrate composed of a mixture of soil, washed sand, and earthworm humus, in a proportion of 84, 15, and 1% (on mass basis), respectively. After sowing, irrigation was performed daily with low-salinity water (ECw = 0.4 dS m^{-1}) to keep the substrate close to the field capacity level.

Transplanting was carried out when the seedlings reached 50 cm in height and started producing tendrils (at 45 days after sowing - DAS). After transplanting, all lysimeters were irrigated with low-salinity water (0.4 dS m^{-1}) maintaining the soil moisture at field capacity. Plants were supported by a vertical trellis system, constructed using round galvanized steel wire no. 12, fixed at 1.7 m height from the surface of the soil in the lysimeter. The treatments began to be applied when the main stem of the plants reached trellis height.

A nylon string was used to hold the plants and when the main branch grew 10 cm above trellis height, the first pruning was performed to induce the growth of secondary branches. When the secondary branches reached one meter in length, second pruning was performed to induce the growth of tertiary branches and formation of the "curtain"; when they reached a 20 cm distance from the ground, the third pruning was performed to avoid contact with the soil. During the whole experiment, unwanted branches, as well as tendrils, were eliminated.

Plants were grown in drainage lysimeters (height of 70 cm, bottom diameter of 57 cm and upper opening of 57 cm) at a spacing of 1.5 m between rows and 2 m between plants. At the bottom of the lysimeters, two holes were drilled and connected to drains 18 mm in diameter and 20 cm in length. Then, a geotextile (Bidim OP 30) was placed at the bottom to prevent clogging of the drains, followed by a layer of crushed stone to facilitate drainage. To collect the drained volume relative to the leaching fraction, a 2-L plastic bottle was placed below each drain and the drainage volume was determined and used to obtain the soil water balance.

Irrigation waters were obtained by the dissolution of sodium chloride (NaCl), calcium chloride ($CaCl_2.2H_2O$), and magnesium chloride ($MgCl_2.6H_2O$), according to the pre-established proportions, based on the electrical conductivity of the water from the supply network of the city of Campina Grande, PB, considering the relationship between ECw and salt concentration, according to Richards (1954), as shown in Eq. 1:

$$Q\ (mmol_c\ L^{-1}) = 10 \times ECw\ (dS\ m^{-1}) \quad (1)$$

Where:

Q = Quantity of salts to be dissolved ($mmol_c\ L^{-1}$);

ECw = Desired increase in electrical conductivity of water (dS m^{-1}).

The salts used (NaCl; $CaCl_2.2H_2O$; $MgCl_2.6H_2O$) had a purity of 99.9, 74, and 100%, respectively. After preparation and ECw calibration, the waters were stored in 100-L plastic containers, properly identified and closed to avoid evaporation.

Irrigation was carried out daily, applying the volume of water in such a way to maintain soil moisture close to the maximum water holding capacity. In each irrigation the volume of water to be applied was determined to meet the water need of the plants, through a root zone water balance (Eq. 2), obtained by the difference between the volume applied and the volume drained, calculated weekly. To avoid the accumulation of salts in the root zone, a leaching fraction of 0.15 (Ayers & Westcot, 1999) was also applied weekly and these characteristics were used in calculations to determine the leaching fraction.

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

Where:

VI = volume of water to be applied in the irrigation event (mL);

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

Vd = volume drained (mL);

LF = Leaching fraction.

At the time of transplanting, fertilization was performed according to São José et al. (2000), applying 250 g of single superphosphate and 100 g of potassium chloride (60% K_2O) and at the beginning of flowering, 150 g of single superphosphate per plant were applied. Nitrogen and potassium fertilizations were performed monthly, using ammonium sulfate as the source of nitrogen and potassium chloride as a source of potassium. In the crop growth stage, the 1N:1K ratio was used based on 10 g of nitrogen; from the beginning of flowering, the N dose was increased to 20 and the K dose to 30 g, increasing the N:K ratio to 1:1.5. Foliar fertilization was also performed monthly with micronutrients.

Phytosanitary control was performed when necessary using agrochemicals, according to recommendations for the crop and with doses recommended by the manufacturers of each product. Weed control was performed between the rows of the drainage lysimeters and around the plant collar through manual weeding. In addition, scarification operations was also performed manually to eliminate invasive plants around the plant collar and loosen up the surface layer of the soil.

Effects of the different treatments on the sour passion fruit crop were measured at 90 and 180 DAT by evaluating stem growth using the absolute growth rate (AGR_{SD}) and relative growth rate (RGR_{SD}) and at 180 DAT by evaluating the photosynthetic pigments: chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) contents, carotenoids (Carot), and photochemical efficiency with initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm).

Stem diameter was measured with a digital caliper at 3 cm from the soil surface and its data were used to calculate the absolute (AGR_{SD}) and relative (RGR_{SD}) growth rates according to the methodology of Benincasa (2003), using Eq. 3 and Eq. 4.

$$AGR = \frac{(SD_2 - SD_1)}{(t_2 - t_1)} \quad (3)$$

where:

AGR_{SD} - absolute growth rate in stem diameter (mm d^{-1}),

SD_1 - stem diameter (mm) at time t_1 (days); and,

SD_2 - stem diameter (mm) at time t_2 (days).

$$RGR = \frac{(\ln SD_2 - \ln SD_1)}{(t_2 - t_1)} \quad (4)$$

where:

RGR_{SD} - relative growth rate in stem diameter (mm mm^{-1} d^{-1}); and,

ln - natural logarithm.

The contents of photosynthetic pigments (chlorophylls *a* and *b* and carotenoids) were quantified according to the laboratory method developed by Arnon (1949). From the extracts, the concentrations of chlorophyll a, chlorophyll b, and carotenoids in the solutions were determined using a spectrophotometer at absorbance wavelengths (ABS) (470, 646, and 663 nm) using Eqs 5, 6, and 7, respectively. Chlorophyll *a*, chlorophyll *b* and carotenoid contents were expressed in mg g^{-1} FM (fresh matter).

Chlorophyll *a* (Chl *a*) = 12.21 ABS_{663} – 2.81 ABS_{646} .... (5)

Chlorophyll *b* (Chl *b*) = 20.13 A_{646} – 5.03 ABS_{663} .... (6)

Carotenoids (Car) = (1000 ABS_{470} – 1.82 Cl a – 85.02 Cl b)/198 .... (7)

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

Chlorophyll *a* fluorescence was measured through initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm) in leaves pre-adapted to the dark using leaf clips for 30 minutes, between 7:00 and 10:00 a.m., in the median leaf of the intermediate productive branch of the plant to ensure that all primary acceptors were oxidized, i.e., the reaction centers were open, using the OS5p pulse-modulated fluorometer from Opti Science.

The data obtained were evaluated by analysis of variance (ANOVA); when significant differences were detected, means comparison test (Tukey p<0.05) and contrasts between treatment means were performed using the statistical program SISVAR-ESAL. Orthogonal contrasts (degrees of freedom of treatment -1) were defined as follows: $\hat{y}_1$ (S_1 vs S_2; S_3; S_4; S_5; S_6; S_7; S_8), $\hat{y}_2$ (S_2 vs S_3), $\hat{y}_3$ (S_2 vs S_4), $\hat{y}_4$ (S_3 vs S_5), $\hat{y}_5$ (S_5 vs S_6; S_7; S_8), $\hat{y}_6$ (S_4 vs S_5) and $\hat{y}_7$ (S_2 vs S_7).

Results and Discussion

According to the summary of analysis of variance (Table 1), there was a significant effect (p<0.01) of the different cationic natures of irrigation water on the absolute and relative growth rates in stem diameter, chlorophyll *a*, chlorophyll *b*, and carotenoids of sour passion fruit plants cv. BRS Rubi do Cerrado at 180 days after transplanting.

Table 1

Summary of the analysis of variance for absolute growth rate (AGR_{SD}) and relative growth rate (RGR_{SD}) in stem diameter, chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and carotenoids (Car) of sour passion fruit plants cv. BRS Rubi do Cerrado irrigated with water of different cationic nature, at 180 days after transplanting

SV/Contrasts#	DF	Mean square				
		AGR_{SD}	RGR_{SD}	Chl *a*	Chl *b*	Car
Blocks	2	0.00018^{ns}	0.000001ns	1377.29^{ns}	766.72^{ns}	48.46^{ns}
CNW	(7)	0.0011**	0.000009**	11113.48**	6215.53**	518.97**
$\hat{y}_1$	1	0.0031**	0.000007^{ns}	48348.55**	15494.40**	1009.10**
$\hat{y}_2$	1	0.000038^{ns}	0,000012*	15844.56**	17068.80**	1574.64**
$\hat{y}_3$	1	0.000228^{ns}	0.000003^{ns}	16252.09**	18634.99**	745.48**
$\hat{y}_4$	1	0.000120^{ns}	0.000023**	49.44^{ns}	834.26^{ns}	7.34^{ns}
$\hat{y}_5$	1	0.0021**	0.000022**	1884.71^{ns}	594.54^{ns}	38.21^{ns}
$\hat{y}_6$	1	0.000106^{ns}	0.000000^{ns}	29.39^{ns}	1207.28^{ns}	93.45^{ns}
$\hat{y}_7$	1	0.0012**	0.000003^{ns}	3871.46^{ns}	11323.93**	769.76**
Residual	14	0.00011	0.000002	1774.65	691.23	80.23
CV (%)		16.39	21.33	22.31	30.22	20.39

#$\hat{y}_1$ (S_1 vs S_2; S_3; S_4; S_5; S_6; S_7; S_8); $\hat{y}_2$ (S_2 vs S_3); $\hat{y}_3$ (S_2 vs S_4); $\hat{y}_4$ (S_3 vs S_5); $\hat{y}_5$ (S_5 vs S_6; S_7; S_8); $\hat{y}_6$ (S_4 vs S_5) and $\hat{y}_7$ (S_2 vs S_7); SV - Source of variation; DF - Degree of freedom; CV - Coefficient of variation; CNW - Cationic nature of water; (*) Significant at 0.05 probability level; (**) Significant at 0.01 probability level; (^{ns}) not significant.

The means comparison test for the absolute growth rate in stem diameter (AGR_{SD}; Figure 1A) showed that plants cultivated with low-salinity water (S_1) obtained the highest mean value (0.096 mm day^{-1}) corresponding to average increments of 0.045, 0.040, 0.06, and 0.048 mm d^{-1} in comparison to plants cultivated with water salinized with Na+ (S_2), Ca^{2+} (S_3), Mg^{2+} (S_4), and Na^+ + Ca^{2+} (S_5), respectively. However, despite obtaining the highest mean value, plants of treatment S_1 did not differ statistically from those grown under treatments S_6, S_7, and S_8. Among the cationic compositions, plants irrigated with water salinized with Na^+ (S_2), Ca^{2+} (S_3), Mg^{2+} (S_4), and Na^+ + Ca^{2+} (S_5) obtained the lowest absolute growth in stem diameter in the period from 90 to 180 DAT (Figure 1A).

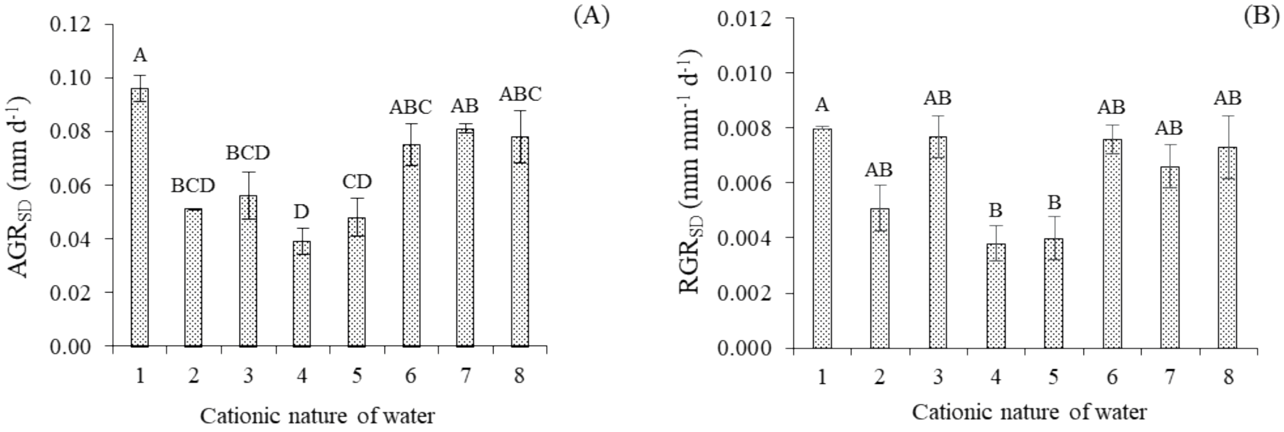

Figure 1. Absolute growth rate - AGR_{SD} (A) and relative growth rate - RGR_{SD} (B) in stem diameter of sour passion fruit plants cv. BRS Rubi do Cerrado, as a function of the cationic nature of irrigation water, in the period from 90 to 180 days after transplanting.
1 - Control; 2 - Na^{+}; 3- Ca^{2+}; 4 - Mg^{2+}; 5 - Na^{+} + Ca^{2+}; 6 - Na^{+} + Mg^{2+}; 7 - Ca^{2+} + Mg^{2+} and 8 - Na^{+} + Ca^{+2} + Mg^{2+}. Bars represent standard error of the mean (n = 3). Means followed by same letters do not differ by Tukey test ($p<0.05$).

As observed for the absolute growth rate, it was verified that for the relative growth rate in stem diameter (RGR_{SD}; Figure 1B), plants irrigated with low-salinity water (S_1) differed significantly from those grown under the treatments S_4 and S_5. However, when comparing plants subjected to the treatments S_2, S_3, S_6, S_7, and S_8 with those in treatment S_1, there was no significant difference among them in terms of RGR_{SD}. The increase in the concentration of soluble salts in the root zone affects the absorption of water and nutrients by plants, causing a reduction in cell turgor, compromising cell expansion, which consequently significantly affects vegetative growth (Khalid & Silva, 2010; N. S. Dias et al., 2016). Reductions in absolute and relative growth rates in plants grown under saline conditions have also been observed in several species, such as in sour passion fruit (Mesquita, Rebequi, Cavalcante, & Souto, 2012; T. J. Dias, Cavalvante, Pereira, Freire, & Souto, 2013), ornamental sunflower (J. A. Santos, Gheyi, Cavalcante, Francilino, & Perez-Marin, 2016), pitomba (Melo et al., 2017), castor bean (Soares et al., 2012), and papaya (Mesquita et al., 2014).

For the contrasts of means referring to the absolute growth rate in stem diameter (Table 2), an estimate of mean showed that plants irrigated with water of the control treatment (ECw = 0.4 dS m^{-1}; S_1) differed significantly from those cultivated with different cationic nature, (S_2; S_3; S_4; S_5; S_6; S_7; and S_8), with an average increase of 0.034 mm d^{-1} in the AGRSD of plants irrigated with low-salinity water compared to those irrigated with water of 3.5 dS m^{-1}. This reduction is possibly related to the osmotic effect, inhibiting the absorption of water and nutrients by the roots and consequently affecting cell expansion and division in plants subjected to salt stress.

When comparing plants that were irrigated with water salinized with Na^{+} + Ca^{2+} (S5) with those cultivated with water composed of Na^+ + Mg^{2+} (S_6), Ca^{2+} + Mg^{2+} (S_7), and Na^+ + Ca^{2+} + Mg^{2+} (S_8), it was possible to observe a reduction of 0.030 mm d^{-1} in AGRSD. A similar effect was also observed when comparing treatment S_2 versus S_7, as plants that received treatment S_2 showed a reduction of 0.029 mm d^{-1}.

For the other contrasts, there was no significant difference for AGRSD between the other treatments. Therefore, it can be inferred that the different cations present in irrigation water similarly affected the absolute growth rate in stem diameter of sour passion fruit plants cv. BRS Rubi do Cerrado.

Table 2

Estimate of the mean for absolute growth rate (AGR_{SD}) and relative growth rate (RGR_{SD}) in stem diameter, chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and carotenoids (Car) contents of sour passion fruit plants cv. BRS Rubi do Cerrado irrigated with water of different cationic nature, in the period from 90 to 180 days after transplanting

Contrasts #	Mean estimate				
	AGRSD (mm d^{-1})	RGRSD (mm mm^{-1} d^{-1})	Chl a (mg g^{-1} FM)	Chl b (mg g^{-1} FM)	Car (mg g^{-1} FM)
$\hat{y}_1$	0.034	ns	135.71	76.82	19.60
$\hat{y}_2$	ns	-0.002	102.77	106.67	32.40
$\hat{y}_3$	ns	ns	104.09	111.46	22.29
$\hat{y}_4$	ns	0.003	ns	ns	ns
$\hat{y}_5$	-0.030	-0.003	ns	ns	ns
$\hat{y}_6$	ns	ns	ns	ns	ns
$\hat{y}_7$	-0.029	ns	ns	86.88	22.65

#$\hat{y}_1$ (S_1 vs S_2; S_3; S_4; S_5; S_6; S_7; S_8); $\hat{y}_2$ (S_2 vs S_3); $\hat{y}_3$ (S_2 vs S_4); $\hat{y}_4$ (S_3 vs S_5); $\hat{y}_5$ (S_5 vs S_6; S_7; S_8); $\hat{y}_6$ (S_4 vs S_5) and $\hat{y}_7$ (S_2 vs S_7); (ns) not significant.

By analyzing the contrasts of means for the relative growth rate in stem diameter (Table 2), it can be observed that plants irrigated using water salinized with sodium (S2) differed significantly from those irrigated with water composed of calcium (S_3) with an estimated reduction of 0.002 mm mm^{-1} day^{-1} in plants cultivated under S_2. When comparing treatments S_3 vs S_5, there was an increase of 0.003 mm mm^{-1} d^{-1} in the relative growth rate in plants irrigated with water salinized by the treatment S_3 (Table 2). Conversely, the RGR_{SD} of plants irrigated using water with sodium + calcium (S_5) decreased by 0.003 mm mm^{-1} day^{-1} compared to those cultivated with water containing sodium + magnesium (S_6), calcium + magnesium (S_7), and sodium + calcium + magnesium (S_8).

There was no significant effect for the other contrast means ($\hat{y}_1$, $\hat{y}_3$, $\hat{y}_6$, and $\hat{y}_7$), which leads to the conclusion that the different cations studied similarly affected the relative growth rate in stem diameter of sour passion fruit cv. BRS Rubi do Cerrado.

The mean comparison test (Figure 2A) shows that there was a significant difference between the treatments for chlorophyll a. Plants irrigated with low-salinity water (S_1) obtained the highest mean value (307.55 mg g^{-1} FM) but did not differ significantly from those in treatments S2 and S7, which obtained mean values of 250.99 and 200.19 mg g^{-1} FM, respectively. It was observed that plants subjected to treatment S_1 differed statistically from those cultivated with water salinized by the treatments S_3, S_4, S_5, S_6, and S_8. It was observed that, except for treatments S_2 and S_7, the greatest reduction in chlorophyll a synthesis was obtained when plants were irrigated under the highest electrical conductivity (ECw = 3.5 dS m^{-1}), regardless of the cationic nature of the water.

These results are in agreement with Ayers and Westcot (1999), who classified the sour passion fruit crop as sensitive to salinity. Reduction in chlorophyll biosynthesis in plants subjected to salt concentrations above their tolerable level may possibly be related to the increase in the chlorophyllase enzyme, which acts by degrading the molecules of this photosynthesizing pigment (Freire, Cavalcante, Nascimento, & Rebequi, 2013). Reduction in chlorophyll content can be considered a salt stress acclimation mechanism of plants, which aims to attenuate energy expenditure by reducing the capture of light energy, thereby reducing the flow of electrons to the electron transfer chain avoiding possible photooxidative stresses (A. R. A. Silva, Bezerra, Lacerda, Sousa, & Chagas, 2016).

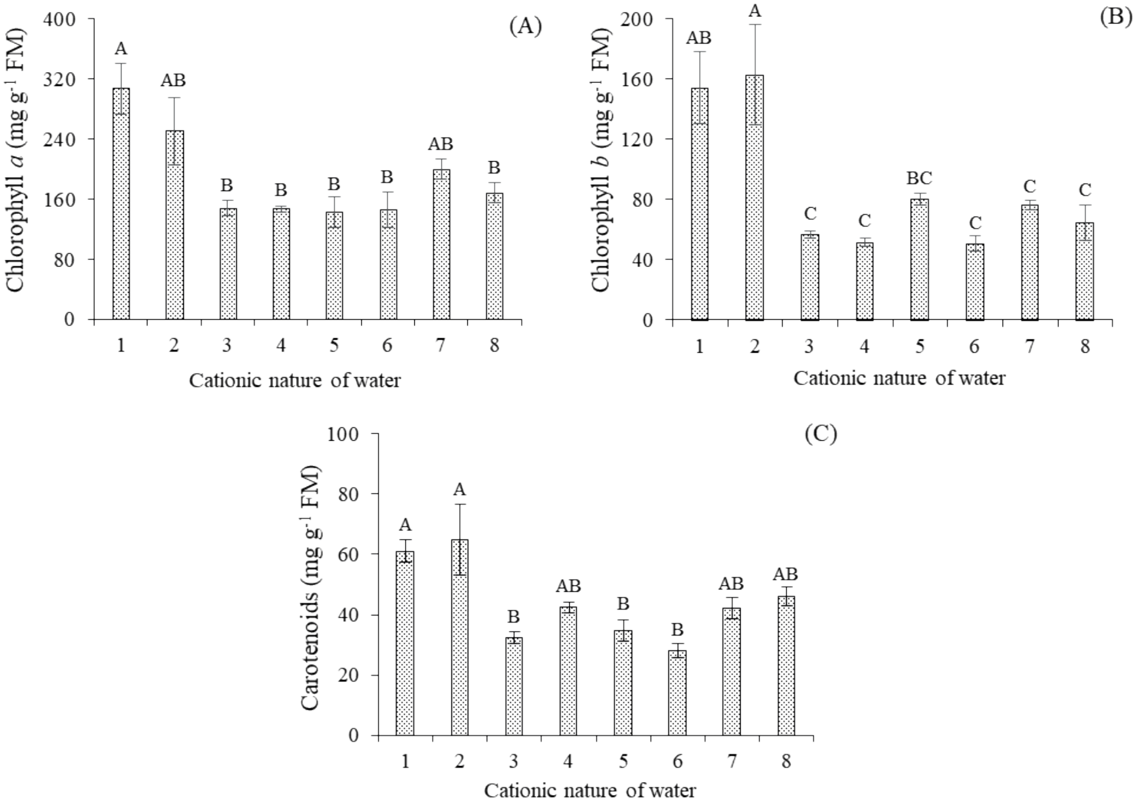

Figure 1. Chlorophyll *a* (A), chlorophyll *b* (B) and carotenoids (C) of sour passion fruit plants cv. BRS Rubi do Cerrado, as a function of the cationic nature of irrigation water, at 180 days after transplanting.
1 - Control; 2 - Na^{+}; 3 - Ca^{2+}; 4 - Mg^{2+}; 5 - Na^{+} + Ca^{2+}; 6 - Na^{+} + Mg^{2+}; 7 - Ca^{2+} + Mg^{2+} and 8 - Na^{+} + Ca^{+2} + Mg^{2+}. Bars represent standard error of the mean (n = 3). Means followed by same letters do not differ by Tukey test ($p<0.05$).

Cavalcante, Dias, Nascimento and Freire (2011) observed a reduction in the photosynthetic efficiency of passion fruit plants subjected to irrigation with saline water at an electrical conductivity above 2.5 dS m^{-1}, at 448 days after transplanting. Wanderley et al. (2018) also observed similar effects on sour passion fruit seedlings when subjected to increasing levels of electrical conductivity in irrigation water, from 0.3 to 3.1 dS m^{-1}.

Regarding chlorophyll *b* contents (Figure 2B), the mean comparison test showed that plants irrigated with water of the sodium composition (S_2) obtained the highest mean value (163.00 mg g^{-1} FM) but did not differ statistically from plants subjected to the control treatment (S1). It was observed that plants corresponding to the treatment with water salinized with sodium (S_2) differed statistically from all others that were subjected to the other cationic compositions of irrigation water with electrical conductivity of 3.5 dS m^{-1} (S_3, S_4, S_5, S_6, S_7, and S_8).

The use of water with high salt content, besides causing problems of ionic toxicity and nutritional imbalance, can lead to complications, such as photoinhibition, photooxidation of chloroplasts, degradation of photosynthetic pigments, enzymatic inactivation, and lipid peroxidation of cell membranes (Ashraf & Harris, 2013). This is probably caused by reduction in the osmotic potential of the soil solution, which hampers the absorption of water and other essential elements for the perfect functioning of cellular machinery (Barroso, Franke, & Barros, 2010; Islam, Islam, & Biswas, 2017), directly affecting the characteristics of plant growth and development, consequently compromising the production of crops.

Results similar to those found in this study were also observed by Freire et al. (2013), who evaluated the effects of irrigation with saline water (ECw from 0.5 to 4.5 dS m^{-1}) on sour passion fruit and observed that the increase in water salinity levels led to a reduction in chlorophyll b synthesis at 117 days after transplanting.

The responses observed in the present study showed an increase in chlorophyll *a* and *b* contents when plants were irrigated using water with a high salt concentration (ECw = 3.5 dS m^{-1}), corresponding to the treatment composed of water with sodium (S_2), compared to the other treatments with high salinity. This is probably due to a process of physiological defense of plants against photooxidation, which may be related to the activation of the mechanism of protection of the photosynthetic apparatus and appears to be a direct implication of the development of chloroplasts, through the increase in the number of thylakoids or even the increase in the number of chloroplasts (M. A. Silva, Santos, Vitorino, & Rhein, 2014; A. R. A. Silva et al., 2016).

The carotenoid content of passion fruit plants varied significantly as a function of the cationic nature of the water (Figure 2C). The mean comparison test showed that plants irrigated with low-salinity water (S_1) and water salinized with sodium (S_2) obtained the highest mean values for the synthesis of carotenoids (61.08 and 64.77 mg g^{-1} FM, respectively) and did not differ statistically from those in the treatments S_4, S_7, and S_8. Although the treatments other than S_1 and S_2 did not differ statistically, the lowest mean values could be observed when plants were subjected to the treatments S_3, S_5, and S_6. The increase in the content of this pigment observed in the present study is possibly related to the greater deleterious effect of the sodium ion in plants, significantly increasing the content of this pigment compared to other ions used in the study.

According to the contrast of means (Table 2) for chlorophyll a, there was a significant effect when the values obtained in plants irrigated with low-salinity water (ECw = 0.4 dS m^{-1}) were compared with plants irrigated with water of higher electrical conductivity (S_2; S_3; S_4; S_5; S_6; S_7; and S_8), as the use of water with a lower salinity level (S_1) led to an increase of 135.71 mg g^{-1} FM in chlorophyll a content compared to the higher salinity level (3.5 dS m^{-1}).

Passion fruit plants irrigated with water salinized with sodium (S_2) increased their chlorophyll a content by 102.77 mg g^{-1} FM in comparison to those that were cultivated with water salinized with calcium (S_3). As observed for S_2 versus S_3, an analysis of the contrast S_2 versus S_4 (magnesium) also showed a significant difference, with an increase in chlorophyll a content of 104.09 mg g^{-1} FM.

There was no significant effect in the comparisons of S_3 versus S_5; S_5 versus S_6, S_7, S_8; S_4 versus S_5; and S_2 versus S_7, indicating similar deleterious effects, regardless of the type of cation(s) present in irrigation water (Table 2).

Analysis of the contrasts of the means for chlorophyll b content of sour passion fruit plants (Table 2) showed that plants irrigated with low-salinity water (S_1) differed statistically from those in the other treatments (S_2; S_3; S_4; S_5; S_6; S_7; and S_8), with an increase of 76.82 mg g^{-1} FM in plants that received the treatment S_1. It is also observed that sour passion fruit plants grown with water salinized with sodium (S_2) had an increase in chlorophyll b content of 106.67 mg g^{-1} FM compared to those subjected to salinity of water salinized with calcium (S_3).

According to the contrast $\hat{y}_3$ (S2 versus S_4), there was an increase in chlorophyll b content of 111.46 mg g^{-1} FM in plants cultivated with water salinized with sodium (S_2) compared to plants that were irrigated with water salinized with magnesium (S_4). The comparison of S_2 versus S_7 (calcium + magnesium) showed an increase of 86.88 mg g^{-1} FM in plants irrigated with water salinized with sodium (S_2). There was no significant difference when comparing the treatments: S_3 versus S_5, S_5 versus S_6, S_7, S_8; and S_4 versus S_5.

Regarding the contrasts of means for carotenoid content (Table 2), there was a significant influence of the different cationic nature of irrigation water (S_2; S_3; S_4; S_5; S_6; S_7; and S_8) compared to the control treatment (S_1), with an increase of 19.60 mg g^{-1} FM in plants irrigated with S_1 in comparison to the other treatments. A significant effect was also observed in the comparison of S_2 versus S_3, where the treatment composed of sodium (S_2) led to an increase of 32.40 mg g^{-1} FM compared to the treatment with water salinized with calcium (S_3).

A comparison of S_2 versus S_4 showed a significant effect, with an increase of 22.29 mg g^{-1} FM in the carotenoid content of plants that received treatment S_2 compared to those subjected to S_4 (magnesium). When comparing plants irrigated using water salinized with sodium (S_2) with those subjected to salinity consisting of calcium + magnesium (S_7), there was an increase of 22.65 mg g^{-1} FM in plants subjected to S_2. No significant effect was observed between the means of the treatments S_3 versus S_5; S_5 versus S_6, S_7, S_8; and S_4 versus S_5.

According to the summary of the analysis of variance (Table 3), there was no significant effect of the cationic nature of irrigation water on any of the fluorescence variables in sour passion fruit plants cv. BRS Rubi do Cerrado at 180 days after transplanting.

Table 3
Summary of the analysis of variance for initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv) and quantum efficiency of photosystem II (Fv/Fm) of sour passion fruit plants cv. BRS Rubi do Cerrado irrigated with water of different cationic nature, at 180 days after transplanting

SV/Contrasts#	DF	Mean square			
		Fo	Fv	Fm	Fv/Fm
Blocks	2	1726.79^{ns}	7128.12 ^{ns}	8292.37 ^{ns}	0.000082 ^{ns}
CNW	(7)	3167.59 ^{ns}	30189.37 ^{ns}	57729.08 ^{ns}	0.000837 ^{ns}
$\hat{y}_1$	1	460.02 ^{ns}	3026.00 ^{ns}	1820.29 ^{ns}	0.000039 ^{ns}
$\hat{y}_2$	1	1176.00 ^{ns}	35574.00 ^{ns}	17604.16 ^{ns}	0.001067 ^{ns}
$\hat{y}_3$	1	3313.50 ^{ns}	80272.66*	95004.16 ^{ns}	0.0031*
$\hat{y}_4$	1	580.16 ^{ns}	2204.16 ^{ns}	5766.00 ^{ns}	0.001233 ^{ns}
$\hat{y}_5$	1	160.44 ^{ns}	2.26 ^{ns}	1284.02 ^{ns}	0.000087 ^{ns}
$\hat{y}_6$	1	2242.66 ^{ns}	20068.16 ^{ns}	9922.66 ^{ns}	0.0034*
$\hat{y}_7$	1	8970.66 ^{ns}	2521.50 ^{ns}	4592.66 ^{ns}	0.000641 ^{ns}
Residual	14	3016.22	13599.98	55534.37	0.00064
CV (%)		7.63	5.95	8.78	3.51

#$\hat{y}_1$ (S_1 vs S_2; S_3; S_4; S_5; S_6; S_7; S_8); $\hat{y}_2$ (S_2 vs S_3); $\hat{y}_3$ (S_2 vs S_4); $\hat{y}_4$ (S_3 vs S_5); $\hat{y}_5$ (S_5 vs S_6; S_7; S_8); $\hat{y}_6$ (S_4 vs S_5) and $\hat{y}_7$ (S_2 vs S_7); SV - Source of variation; DF - Degree of freedom; CV - Coefficient of variation; CNW - Cationic nature of water; (*) Significant at 0.05 probability level; (**) Significant at 0.01 probability level; (^{ns}) not significant.

Conclusions

Sour passion fruit growth was affected by variations in the level of electrical conductivity, regardless of the cationic nature of irrigation water.

The use of water salinized with sodium favors increments in the synthesis of chlorophyll a, chlorophyll b, and carotenoids of passion fruit plants at 180 days after transplanting.

The distinct cationic nature of irrigation water do not influence the fluorescence variables of sour passion fruit at 180 days after transplanting.

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