

## GAS EXCHANGE, CHLOROPLAST PIGMENTS AND GROWTH OF PASSION FRUIT CULTIVATED WITH SALINE WATER AND POTASSIUM FERTILIZATION<sup>1</sup>

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**ABSTRACT** - The objective of this study was to evaluate the gas exchange, chloroplast pigments and growth of 'BRS Rubi do Cerrado' passion fruit as a function of irrigation with saline water and potassium fertilization in the seedling formation stage. The experiment was conducted under greenhouse conditions in the municipality of Pombal-PB, Brazil. A randomized block design was used in 5 x 2 factorial scheme, corresponding to five levels of water electrical conductivity - EC<sub>w</sub> (0.3, 1.1, 1.9, 2.7 and 3.5 dS m<sup>-1</sup>) and two doses of potassium - KD (50 and 100% of the recommendation), with four replicates and two plants per plot. Water salinity from 0.3 dS m<sup>-1</sup> reduced the stomatal opening, transpiration, CO<sub>2</sub> assimilation and inhibited the growth of 'BRS Rubi do Cerrado' passion fruit plants, at 40 days after sowing. There was no CO<sub>2</sub> restriction in the substomatal cavity of passion fruit plants grown under water salinity from 0.3 dS m<sup>-1</sup>. Potassium dose of 150 mg kg<sup>-1</sup> of soil, corresponding to 100%, intensified the effect of salt stress on the assimilation rate and instantaneous carboxylation efficiency in 'BRS Rubi do Cerrado' passion fruit. There was interaction between water salinity levels and potassium doses for the chlorophyll *a* and *b* contents of 'BRS Rubi do Cerrado' passion fruit.

**Keywords:** Salt stress. Potassium. Osmoregulation.

## TROCAS GASOSAS, PIGMENTOS CLOROPLASTÍDICOS E CRESCIMENTO DO MARACUJAZEIRO CULTIVADO COM ÁGUAS SALINAS E ADUBAÇÃO POTÁSSICA

**RESUMO** - Objetivou-se com este trabalho avaliar as trocas gasosas, os pigmentos cloroplastídicos e o crescimento do maracujazeiro 'BRS Rubi do Cerrado' em função da irrigação com águas salinas e adubação potássica, na fase de formação de mudas. O experimento foi conduzido sob condições de casa-de-vegetação no município de Pombal-PB. Foi utilizado o delineamento de blocos casualizados em esquema fatorial 5 x 2, sendo cinco níveis de condutividade elétrica da água - CE<sub>a</sub> (0,3; 1,1; 1,9; 2,7 e 3,5 dS m<sup>-1</sup>) e duas doses de potássio - DK (50 e 100% da recomendação) com quatro repetições e duas plantas por parcela. A salinidade da água a partir de 0,3 dS m<sup>-1</sup> diminuiu a abertura estomática, a transpiração, a assimilação de CO<sub>2</sub> e inibiu o crescimento das plantas de maracujazeiro 'BRS Rubi do Cerrado', aos 40 dias após o semeio. Não houve restrição de CO<sub>2</sub> na cavidade subestomática das plantas de maracujazeiro cultivadas sob salinidade da água a partir de 0,3 dS m<sup>-1</sup>. A dose de potássio de 150 mg kg<sup>-1</sup> de solo, correspondente a 100%, intensificou o efeito do estresse salino sobre a taxa de assimilação e a eficiência instantânea de carboxilação no maracujazeiro 'BRS Rubi do Cerrado'. Houve interação entre os níveis salinos da água e as doses de potássio para os teores de clorofila *a* e *b* do maracujazeiro 'BRS Rubi do Cerrado'.

**Palavras-chave:** Estresse salino. Potássio. Osmorregulação.

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## INTRODUCTION

Belonging to the Passifloraceae family, passion fruit stands out as one of the most cultivated species. In the 2018 season, Brazil stood out as the world's largest passion fruit producer, with an area of approximately 78,502.42 hectares, resulting in the production of 602,651 tons per year. Passion fruit cultivation is carried out in almost all Brazilian states, especially in the Northeast region, which has the largest planted area, where the states of Bahia and Ceará have 15,724 and 6,862 hectares of plantations, with average yields of 10.50 and 17.25 t/ha, respectively (IBGE, 2018).

However, passion fruit production in regions with low water availability, such as in the semiarid region of northeastern Brazil, causes large variations in its production cycle (ODRESCA, 2016). At the same time, the quality of irrigation water in these regions has deteriorated, especially due to increased salt concentrations. In addition, soil salinization combined with inadequate irrigation management is becoming increasingly harmful to agriculture (AREF; RAD, 2012).

Passion fruit irrigation with saline water has been investigated in several studies (DIAS et al., 2012; FREIRE et al., 2012; VIANA et al., 2012). In general, these studies have shown that salinity reduces the growth of branches and several other growth components, besides compromising some chemical characteristics of the fruits when irrigation is carried out with waters of moderate to high salinity. These limitations occur because, under saline conditions, there is a reduction in water availability to plants, due to the reduction in the osmotic potential of the soil solution (JIANG et al., 2012). In addition, salinization leads to nutritional imbalance since excess sodium in the soil solution causes disorder in nutrient absorption, affecting the concentrations of ions such as Ca, Mg and K in the plant (MARSCHNER, 2012).

However, plants have developed a wide range of mechanisms to withstand a variety of stress conditions. Evidence indicates that mineral nutrients, particularly potassium, play a key role in plant resistance to salt stress, and such tolerance to salinity is directly associated with the content of  $K^+$  due to its involvement in osmotic regulation and competition with  $Na^+$  (MARSCHNER, 2012).

Potassium acts directly on passion fruit growth and production, as the main functions of this nutrient in the plant are related to many physiological processes, such as carbon assimilation, photosynthesis, protein synthesis, enzymatic activation, stomatal movement and translocation of organic and inorganic nutrients from soil to plant (ZHANG et al., 2010). In addition, in the metabolism it is involved in the activation of the synthesis of starch, phosphate, sucrose and other enzymes, and in transport of carbohydrates. Under salt stress, K helps

maintain ionic homeostasis and improves plant antioxidant defense, protecting it from oxidative stress (HASANUZZAMAN et al., 2018).

Therefore, there is a need for more accurate research with passion fruit crop irrigated with saline water in the Northeast region, in order to evaluate the deleterious effects of salt stress on this species, as well as to enable the adoption of agronomic strategies, such as potassium fertilization, aiming at an adequate management for the crop under the conditions of the northeastern semiarid region.

In this context, the objective of this study was to evaluate the gas exchange, chloroplast pigments and growth of 'BRS Rubi do Cerrado' passion fruit as a function of irrigation with saline water and potassium fertilization, in the seedling formation stage.

## MATERIAL AND METHODS

The experiment was carried out from March to May 2019 in a protected environment (greenhouse) of the Center for Sciences and Agri-Food Technology - CCTA of the Federal University of Campina Grande - UFCG, located in the municipality of Pombal, Paraíba, PB, Brazil (6°47'20" S latitude and 37°48'01" W longitude; altitude of 194 m).

The treatments resulted from the combination of five salt concentrations in the irrigation water expressed through the electrical conductivity - ECw (0.3; 1.1; 1.9; 2.7 and 3.5 dS  $m^{-1}$ ) associated with two doses of potassium fertilization - KD (50 and 100% of the recommendation of  $K_2O$ ) according to Novais, Neves and Barros (1991). The experimental design was randomized blocks in a 5 x 2 factorial arrangement, with two plants per plot and four replicates, totaling eighty experimental units. The potassium dose relative to 100% of the recommendation corresponded to 150 mg  $K_2O$   $kg^{-1}$  of soil.

Seeds of 'BRS Rubi do Cerrado' passion fruit were used in this study. This cultivar has red- or purplish-peel fruits weighing 120 to 300 grams (average of 170 g), with soluble solids content of 13 to 15 °Brix (average of 14 °Brix) and juice yield around 35%. Higher levels of resistance to the main diseases of passion fruit (viral disease, bacterial disease, anthracnose and scab) and high levels of yield are the two most important characteristics of this cultivar (EMBRAPA, 2012).

In order to obtain passion fruit seedlings, sowing was performed by placing 2 seeds in polyethylene bags with dimensions of 15 x 30 cm, at 1.5 cm depth and equidistantly distributed (Figure 1A), supported on benches at 0.8 m height from the soil. The bags were filled with a 2:1:1 ratio of sandy loam Entisol, sand and organic matter (well-aged bovine manure), from the rural area of the

municipality of São Domingos, PB, whose chemical and physical characteristics (Table 1) were obtained according to the methodology proposed by Donagema et al. (2011).

All fertilizations were performed as top-dressing, according to the recommendation for fertilization in pot experiments contained in Novais, Neves and Barros (1991), using the amounts of 100 and 300 mg kg<sup>-1</sup> of soil of nitrogen and phosphorus (P<sub>2</sub>O<sub>5</sub>), respectively, in the form of Monoammonium

Phosphate (MAP), applied via irrigation water at 15 and 30 days after sowing (DAS). Potassium fertilization was split into portions applied via fertigation, at 10-day intervals, in quantities of 75 and 150 mg of K<sub>2</sub>O kg<sup>-1</sup> of soil in each container for the treatments K<sub>1</sub> and K<sub>2</sub>, respectively, using potassium chloride as a source, and the K<sub>2</sub> dose corresponded to 100% of the recommendation of Novais, Neves and Barros (1991).

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

		Chemical characteristics						
pH H <sub>2</sub> O)	OM	P	K <sup>+</sup>	Na <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Al <sup>3+</sup>	H <sup>+</sup>
(1:2.5)	(g kg <sup>-1</sup> )	(mg kg <sup>-1</sup> )	.....cmol <sub>c</sub> kg <sup>-1</sup> .....					
5.58	2.93	39.2	0.23	1.64	9.07	2.78	0.0	8.61
..... Chemical characteristics.....				..... Physical characteristics.....				
EC <sub>se</sub>	CEC	SAR	ESP	Size fraction (g kg <sup>-1</sup> )			Water content (dag kg <sup>-1</sup> )	
(dS m <sup>-1</sup> )	(cmol <sub>c</sub> kg <sup>-1</sup> )	(mmol L <sup>-1</sup> ) <sup>0.5</sup>	%	Sand	Silt	Clay	33.42 kPa <sup>1</sup>	1519.5 kPa <sup>2</sup>
2.15	22.33	0.67	7.34	572.7	100.7	326.6	25.91	12.96

pH – Hydrogen potential, OM – Organic matter: Walkley-Black Wet Digestion; Ca<sup>2+</sup> and Mg<sup>2+</sup> extracted with 1 M KCl at pH 7.0; Na<sup>+</sup> and K<sup>+</sup> extracted with 1 M NH<sub>4</sub>OAc at pH 7.0; Al<sup>3+</sup>+H<sup>+</sup> extracted with 0.05 M CaOAc at pH 7.0; EC<sub>se</sub> - Electrical conductivity of the saturation extract; CEC - Cation exchange capacity; SAR - Sodium adsorption ratio of the saturation extract; ESP - Exchangeable sodium percentage; <sup>1,2</sup> referring to field capacity and permanent wilting point.

The water used for irrigation in the treatment of lowest salinity (0.3 dS m<sup>-1</sup>) came from the public supply system of Pombal, PB, whereas the other salinity levels were prepared in such a way to have an equivalent proportion of 7:2:1 for Na:Ca:Mg, respectively, from the salts NaCl, CaCl<sub>2</sub>.2H<sub>2</sub>O and MgCl<sub>2</sub>.6H<sub>2</sub>O, a ratio that prevails in sources of water used for irrigation in small properties of northeastern Brazil.

Irrigation waters of the highest salinity levels were prepared considering the relationship between EC<sub>w</sub> and salt concentration (mmol<sub>c</sub> L<sup>-1</sup> = 10\*EC<sub>w</sub> (dS m<sup>-1</sup>)), according to Richards (1954), checking the values with a conductivity meter (reading adjusted to temperature of 25 °C). After preparation, the waters were stored in 80-L plastic containers, one for each EC<sub>w</sub> level studied, properly protected to avoid evaporation, entry of rainwater and contamination with materials that may compromise their quality.

After sowing, irrigation was performed daily at 17:00 h, applying in each container the volume corresponding to that obtained by the water balance, based on the volume consumed (VC), considering the water volume applied to plants (VA) in the previous day; VD is the volume drained, quantified in the morning of the next day and the desired leaching fraction - LF (20%), in order to avoid excessive accumulation of salts from irrigation water in the root zone.

At 40 DAS, the following gas exchange variables were evaluated: stomatal conductance (gs) (mol m<sup>-2</sup> s<sup>-1</sup>), transpiration (E) (mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>),

CO<sub>2</sub> assimilation rate (A) (μmol m<sup>-2</sup> s<sup>-1</sup>) and internal CO<sub>2</sub> concentration (Ci) (μmol mol<sup>-1</sup>). These data were then used to estimate intrinsic water use efficiency (WUEi) - A/gs (μmol CO<sub>2</sub> mol H<sub>2</sub>O<sup>-1</sup>), instantaneous carboxylation efficiency (CEi) - A/Ci (μmol m<sup>-2</sup> s<sup>-1</sup>/μmol m<sup>-2</sup> s<sup>-1</sup>). Such measurements were performed with a gas exchange meter for plants, containing an infrared gas analyzer - IRGA (Infrared Gas Analyser, LCpro – SD model), from ADC BioScientific, UK. The procedure for measuring the respective variables was performed by adopting as a criterion the third fully expanded leaf counted from the apical bud.

Chlorophyll *a*, chlorophyll *b*, and carotenoid contents were determined in samples of 5 discs of the lamina of the third mature leaf from the apex, as indicated in the methodology proposed by Arnon (1949). From the extracts, the concentrations of these compounds in the solutions were measured using a spectrophotometer at the absorbance (ABS) wavelength (470, 646, and 663 nm), according to the following equations (Equations 1, 2 and 3):

$$Chl\ a = 12.21\ ABS_{663} - 2.81\ ABS_{646} \quad (1)$$

$$Chl\ b = 20.13\ A_{646} - 5.03\ ABS_{663} \quad (2)$$

$$Car = (1000\ ABS_{470} - 1.82\ Cla - 85.02\ Clb)/198 \quad (3)$$

Where: Chl *a* = Chlorophyll *a*; Chl *b* = Chlorophyll *b*; and Car =Total carotenoids. The values obtained for chlorophyll *a*, chlorophyll *b* and

carotenoid contents in the leaves were expressed in  $\text{mg g}^{-1}$  of fresh matter - FM ( $\text{mg g}^{-1}$  FM).

Stem diameter was measured 5 cm above the collar, with a digital caliper. Leaf area was obtained by measuring the length and width of all leaves of the plants, following the methodology described by Cavalcante et al. (2002), according to Eq 4:

$$LA = \sum 0.81 x \quad (4)$$

Where: LA - Leaf area ( $\text{cm}^2$ ) and x - Product of length by width ( $\text{cm}^2$ ).

Plant height was obtained by measuring the length of the aerial part, in centimeters, from the soil level (plant collar) to the insertion of the apical meristem.

The data were subjected to the analysis of variance by F test and, when significant, polynomial regression analysis was performed for the factors salinity levels and potassium doses

(at 0.05 probability level) and, when there was significant interaction between factors, salinity levels were further analyzed considering each potassium dose, using the statistical program SISVAR-ESAL.

## RESULTS AND DISCUSSION

According to the analysis of variance summary (Table 2), there was significant effect of water salinity levels on the stomatal conductance ( $g_s$ ), transpiration ( $E$ ), intercellular  $\text{CO}_2$  concentration ( $C_i$ ),  $\text{CO}_2$  assimilation rate ( $A$ ), instantaneous carboxylation efficiency (CEi) of 'BRS Rubi do Cerrado' passion fruit plants. Potassium doses had significant influence only on  $A$  and CEi. The interaction between factors (SL x KD) did not cause a significant effect on any of the variables analyzed, at 40 DAS.

**Table 2.** Summary of analysis of variance for stomatal conductance ( $g_s$ ), transpiration ( $E$ ), intercellular  $\text{CO}_2$  concentration ( $C_i$ ),  $\text{CO}_2$  assimilation rate ( $A$ ), instantaneous carboxylation efficiency (CEi) and intrinsic water use efficiency (WUEi) of 'BRS Rubi do Cerrado' passion fruit plants cultivated with saline waters and potassium doses, at 40 days after sowing (DAS).

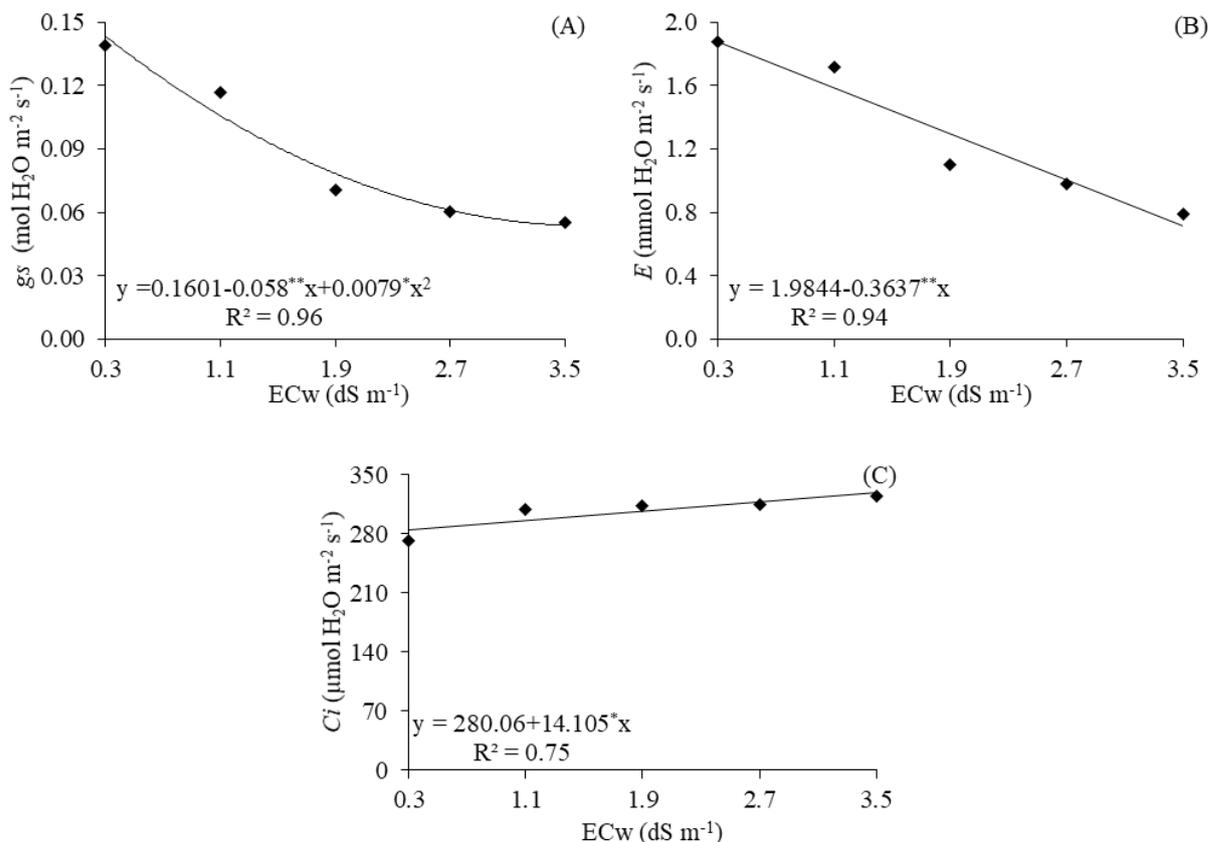
Source of variation	DF	Mean squares					
		$g_s$	$E$	$C_i$	$A$	CEi	WUEi
Saline levels (SL)	4	0.01**	1.81**	3406.72*	16.15**	0.0003**	27.51 <sup>ns</sup>
Linear regression	1	0.04**	6.77**	10245.32*	56.40**	0.001**	74.21 <sup>ns</sup>
Quadratic regression	1	0.002*	0.11 <sup>ns</sup>	1933.35 <sup>ns</sup>	7.48*	0.0001*	4.92 <sup>ns</sup>
K dose (KD)	1	0.0007 <sup>ns</sup>	0.02 <sup>ns</sup>	810.00 <sup>ns</sup>	11.62*	0.0001*	32.88 <sup>ns</sup>
Interaction (SL x KD)	4	0.0005 <sup>ns</sup>	0.24 <sup>ns</sup>	2017.89 <sup>ns</sup>	2.53 <sup>ns</sup>	0.0005 <sup>ns</sup>	15.09 <sup>ns</sup>
Blocks	3	0.0004 <sup>ns</sup>	0.12 <sup>ns</sup>	617.80 <sup>ns</sup>	0.22 <sup>ns</sup>	0.00007 <sup>ns</sup>	66.51 <sup>ns</sup>
Residual	27	0.0008	0.19	1077.35	1.23	0.00001	29.24
CV (%)		32.80	34.31	10.70	22.80	22.53	14.31

<sup>ns</sup>, \*\*, \* respectively not significant, significant at  $p < 0.01$  and  $p < 0.05$ ; DF - Degree of freedom; CV - Coefficient of variation.

The stomatal conductance of 'BRS Rubi do Cerrado' passion fruit plants decreased quadratically as the levels of irrigation water electrical conductivity increased. The regression equation (Figure 1A) shows that plants grown under ECw of  $0.3 \text{ dS m}^{-1}$  had the highest stomatal conductance ( $0.143 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$ ), whereas the lowest  $g_s$  ( $0.054 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$ ) was obtained under the highest water salinity level ( $3.5 \text{ dS m}^{-1}$ ). By comparing the  $g_s$  of plants irrigated with  $3.5 \text{ dS m}^{-1}$  water to the value of plants receiving  $0.3 \text{ dS m}^{-1}$ , it is possible to note a reduction of 62.24% ( $0.089 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$ ). When plants are subjected to salt stress, the primary effect is the closure of stomata, as a strategy to increase stomatal resistance to the water vapor flow from the leaves to the external atmosphere in order to keep the water potential in the leaves and avoid dehydration of guard cells, which results in restriction of the normal  $\text{CO}_2$  flow towards the carboxylation site (Silva et al., 2015). Corroborating the present study, Souza et al. (2016) in a study with citrus (scion/rootstock combinations),

evaluating the effects of irrigation with saline waters (ECw:  $0.6$  to  $3.0 \text{ dS m}^{-1}$ ) on gas exchange, found that ECw from  $0.6 \text{ dS m}^{-1}$  promoted a marked reduction in stomatal conductance, at 210 days after the beginning of flowering.

Leaf transpiration (Figure 1B) of 'BRS Rubi do Cerrado' passion fruit plants decreased linearly by 18.32% per unit increase in the levels of water electrical conductivity. It can be observed through the regression equation (Figure 1B) that plants grown under ECw of  $3.5 \text{ dS m}^{-1}$  had a reduction in  $E$  of 62.06% ( $1.163 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$ ) compared to those receiving the lowest salinity level ( $0.3 \text{ dS m}^{-1}$ ). Such reduction in  $E$  is related to stomatal closure (Figure 1A), standing out as a strategy to decrease the absorption rate of toxic ions ( $\text{Na}^+$  and  $\text{Cl}^-$ ). Andrade (2018), evaluating the gas exchange of yellow passion fruit as a function of irrigation with waters of different salinity levels (ECw:  $0.7$  to  $2.8 \text{ dS m}^{-1}$ ), also found that the increase in ECw levels resulted in a reduction in leaf transpiration rate, equal to 16.01% per unit increment in ECw.



**Figure 1.** Stomatal conductance –  $g_s$  (A), transpiration -  $E$  (B) and intercellular  $\text{CO}_2$  concentration -  $C_i$  (C) of ‘BRS Rubi do Cerrado’ passion fruit plants as a function of irrigation water salinity - ECw, 40 days after sowing.

Contrary to what was observed for stomatal conductance (Figure 1A) and leaf transpiration (Figure 1B), the intercellular  $\text{CO}_2$  concentration (Figure 1C) of passion fruit plants increased linearly as a function of water salinity levels, by 5.03% per unit increase in irrigation water electrical conductivity. Comparatively, it can be noted that plants under ECw of  $0.3 \text{ dS m}^{-1}$  had a decrease of 13.70% ( $45.13 \mu\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$ ) compared to those that received the highest level of water salinity. Thus, it is evidenced that, despite the reduction in stomatal conductance (Figure 1A), there was no restriction on the influx of  $\text{CO}_2$  into the substomatal cavity of the plants. According to Walter, Rosa and Streck (2015), smaller stomatal opening contributes to reduction in water losses by transpiration through the stomata, but does not compromise  $\text{CO}_2$  concentration in the leaf. In a study with passion fruit under irrigation with water of low and high salinity (ECw:  $0.5$  and  $4.5 \text{ dS m}^{-1}$ ), Freire et al. (2014) concluded that salt stress does not interfere with the intercellular concentration of  $\text{CO}_2$ .

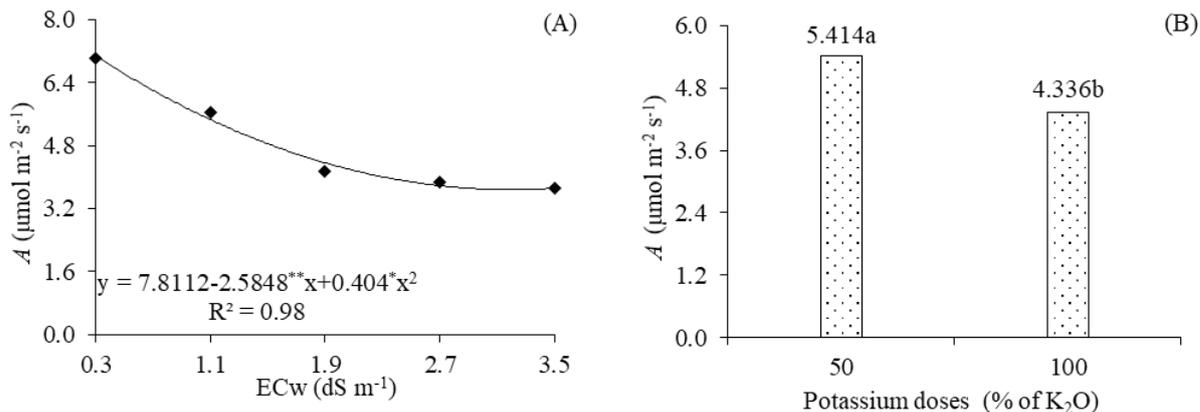
Irrigation water salinity negatively affected the  $\text{CO}_2$  assimilation rate of passion fruit plants. According to the regression equation (Figure 2B), it can be noted that the best fit to the data was obtained with the quadratic model, whose maximum estimated value for  $A$  was  $7.072 \mu\text{mol m}^{-2} \text{s}^{-1}$ , observed in plants under ECw of  $0.3 \text{ dS m}^{-1}$ ,

decreasing sharply from this salinity level and reaching the minimum value of  $3.713 \mu\text{mol m}^{-2} \text{s}^{-1}$  in plants cultivated under water salinity of  $3.5 \text{ dS m}^{-1}$ . There was a reduction of 47.49% in the  $\text{CO}_2$  assimilation rate of plants irrigated using water with ECw of  $3.5 \text{ dS m}^{-1}$  compared to those under  $0.3 \text{ dS m}^{-1}$ . The reduction of  $\text{CO}_2$  assimilation rate in passion fruit plants (Figure 2A) may be related to the action of factors of non-stomatal origin, considering that there was no reduction in the intercellular  $\text{CO}_2$  concentration in the substomatal cavity (Figure 1C). In addition, the unavailability of ATP and NADPH in the Calvin cycle and inhibition of ribulose-1,5-bisphosphate carboxylase/oxygenase stand out as the main factors responsible for the reduction in  $\text{CO}_2$  assimilation rate (Machado et al., 2005). Evaluating the effects of salt stress on the West Indian cherry cv. ‘BRS 366 Jaburu’, Dias et al. (2019) found that the increase in water salinity from  $0.8$  to  $3.8 \text{ dS m}^{-1}$  caused reduction in the  $\text{CO}_2$  assimilation rate of 49.13% ( $3.53 \mu\text{mol m}^{-2} \text{s}^{-1}$ ).

Potassium doses significantly influenced the  $\text{CO}_2$  assimilation rate of ‘BRS Rubi do Cerrado’ passion fruit plants (Table 2). According to the means comparison test (Figure 2B), the  $\text{CO}_2$  assimilation rate of plants grown under  $\text{K}_2\text{O}$  dose of 100% of the recommendation differed statistically from those receiving 50% of the  $\text{K}_2\text{O}$  recommendation. A reduction of 19.91% ( $1.078$

$\mu\text{mol m}^{-2} \text{s}^{-1}$ ) in *A* was observed between the lowest and highest doses of  $\text{K}_2\text{O}$ . Despite the functions performed by potassium in the maintenance of ionic balance and turgor of cells, through the control of stomatal opening and closure (GURGEL; GHEYI; OLIVEIRA, 2010), in this study the highest dose of  $\text{K}_2\text{O}$  contributed to a reduction in the  $\text{CO}_2$  assimilation rate of passion fruit plants. This

situation may be related to the source of potassium used in this study (KCl), as this fertilizer has a high salt index (116.3) and, when associated with the use of waters with high salt concentrations, it may have induced a reduction in the osmotic potential of the soil solution, hampering the absorption of water and nutrients by plants.

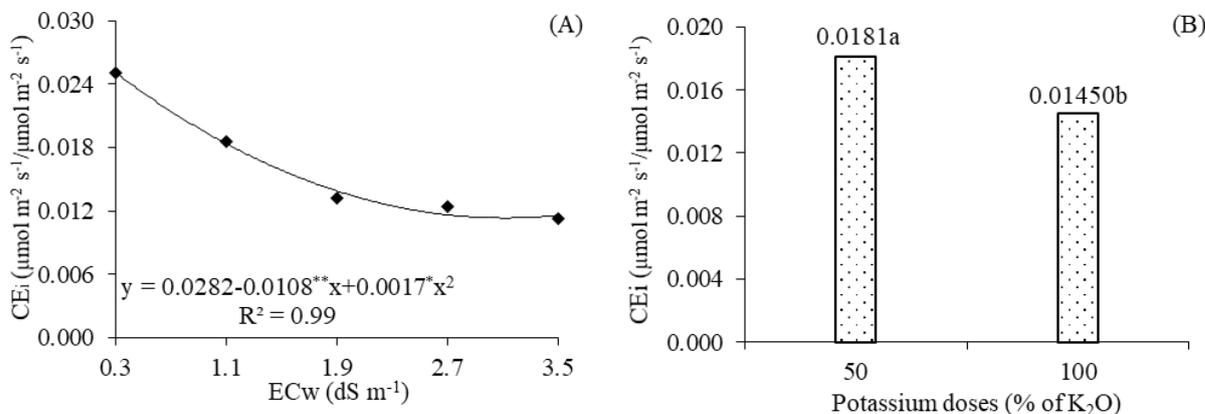


Means followed by the same letter do not differ by Tukey test ( $p < 0.05$ ). The potassium dose relative to 100% of the recommendation corresponded to 150 mg  $\text{K}_2\text{O kg}^{-1}$  of soil.

**Figure 2.**  $\text{CO}_2$  assimilation rate – *A* of ‘BRS Rubi do Cerrado’ passion fruit plants as a function of irrigation water salinity – ECw (A) and potassium doses (B), at 40 days after sowing.

The instantaneous carboxylation efficiency of passion fruit plants decreased quadratically due to salt stress. Based on the regression equation (Figure 3A), the highest estimated CE<sub>i</sub> of 0.0251 ( $\mu\text{mol m}^{-2} \text{s}^{-1} / \mu\text{mol m}^{-2} \text{s}^{-1}$ ) was obtained in plants grown under ECw of 0.3 dS  $\text{m}^{-1}$ . On the other hand, the lowest CE<sub>i</sub> ( $\mu\text{mol m}^{-2} \text{s}^{-1} / \mu\text{mol m}^{-2} \text{s}^{-1}$ ) was observed under water electrical conductivity of 3.5 dS  $\text{m}^{-1}$ . It can also be noted that passion fruit plants irrigated with 3.5 dS  $\text{m}^{-1}$  water reduced their CE<sub>i</sub> by 55.8% or 0.014 ( $\mu\text{mol m}^{-2} \text{s}^{-1} / \mu\text{mol m}^{-2} \text{s}^{-1}$ ), compared to those under the lowest level of water salinity (0.3 dS  $\text{m}^{-1}$ ). In plants grown under salt stress conditions, the

reduction in CE<sub>i</sub> may be related to metabolic restrictions in the Calvin cycle (SOUSA et al., 2016) and the occurrence of non-stomatal factors acting on the photosynthetic apparatus of passion fruit plants, such as inhibition of the enzymatic activity of Ribulose-1,5-bisphosphate carboxylase/oxygenase, due to the reduced availability of ATP and NADPH (MACHADO et al., 2005; SÁ et al., 2017). In a study with West Indian cherry, cv. ‘BRS 366 Jaburu’, under salt stress conditions (ECw of 0.8 and 3.8 dS  $\text{m}^{-1}$ ), Dias et al. (2018) found a reduction of 56.75% in CE<sub>i</sub> between plants irrigated with ECw of 0.8 and 3.8 dS  $\text{m}^{-1}$ .



Means followed by the same letter do not differ by Tukey test ( $p < 0.05$ ). The potassium dose relative to 100% of the recommendation corresponded to 150 mg  $\text{K}_2\text{O kg}^{-1}$  of soil.

**Figure 3.** Instantaneous carboxylation efficiency – CE<sub>i</sub> of ‘BRS Rubi do Cerrado’ passion fruit plants as a function of irrigation water salinity – ECw (A) and potassium doses (B), at 40 days after sowing.

By analyzing the instantaneous carboxylation efficiency of passion fruit as a function of potassium doses at 40 DAS, it was observed that the CEi was statistically higher in plants grown under the lowest dose of K<sub>2</sub>O than in those under 100% of the fertilization recommended by Novais, Neves and Barros (1991). There was a reduction of 0.0036 ( $\mu\text{mol m}^{-2} \text{s}^{-1}/\mu\text{mol m}^{-2} \text{s}^{-1}$ ) or 19.89% in the CEi of the plants fertilized with 100% K<sub>2</sub>O compared to those under the dose of 50% K<sub>2</sub>O. Although the value recommended by Novais, Neves and Barros (1991) was supplied at the highest dose of K<sub>2</sub>O (150 mg kg<sup>-1</sup> of soil), the availability of potassium in the soil solution in greater amount than the nutritional need of the crop may interfere in the absorption of Ca<sup>2+</sup> and Mg<sup>2+</sup> ions, due to the competition of these elements for the same absorption sites in the root

tissues of plants, inducing deficiency of calcium and magnesium (SILVA; TREVIZAM, 2015). Thus, the action of non-stomatal factors such as nutritional deficiency stands out as a limiting factor for reduction in the instantaneous carboxylation efficiency of plants under salt stress conditions.

According to the analysis of variance summary (Table 3), there was significant effect ( $p < 0.01$ ) of salinity levels on the contents of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*) and carotenoids (Car), plant height (PH), stem diameter (SD) and leaf area (LA) of passion fruit plants, at 40 DAS. There was a significant effect ( $p < 0.05$ ) of potassium doses on Chl *a*. The interaction between factors (SL x KD) significantly influenced ( $p < 0.05$ ) the contents of chlorophyll *a* and *b*.

**Table 3.** Summary of analysis of variance for the contents of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), carotenoids (Car), plant height (PH), stem diameter (SD) and leaf area (LA) of 'BRS Rubi do Cerrado' passion fruit plants cultivated with saline water and potassium doses, at 40 days after sowing (DAS).

Source of variation	DF	Mean squares					
		Chl <i>a</i>	Chl <i>b</i>	Car	PH	SD	LA
Saline levels (SL)	4	142.46**	14.32**	10.10**	1008.55**	2.14**	55787.82**
Linear regression	1	546.02**	53.08**	40.15**	3413.10**	8.52**	206033.63**
Quadratic regression	1	6.05 <sup>ns</sup>	2.56 <sup>ns</sup>	0.11 <sup>ns</sup>	562.95*	0.002 <sup>ns</sup>	12898.18 <sup>ns</sup>
K dose (KD)	1	28.56*	0.91 <sup>ns</sup>	0.02 <sup>ns</sup>	0.61 <sup>ns</sup>	0.16 <sup>ns</sup>	12304.41 <sup>ns</sup>
Interaction (SL x KD)	4	35.59*	4.49*	1.60 <sup>ns</sup>	47.51 <sup>ns</sup>	0.03 <sup>ns</sup>	26092.66 <sup>ns</sup>
Blocks	3	10.21 <sup>ns</sup>	0.11 <sup>ns</sup>	0.60 <sup>ns</sup>	159.65 <sup>ns</sup>	0.24 <sup>ns</sup>	68644.12 <sup>ns</sup>
Residual	27	4.18	0.83	0.66	61.84	0.20	19879.39
CV (%)		18.21	25.40	20.40	26.56	13.06	28.69

<sup>ns</sup>, \*\*, \* respectively not significant, significant at  $p < 0.01$  and  $p < 0.05$ ; DF - Degree of freedom; CV - Coefficient of variation.

The chlorophyll *a* content of the passion fruit was significantly affected by the interaction between factors (SL x KD), at 40 DAS. According to regression equations (Figure 4A), a quadratic model fitted to the Chl *a* contents of plants fertilized with 50 and 100% of the recommendation of K<sub>2</sub>O. For passion fruit plants fertilized with 50% K<sub>2</sub>O, the maximum value for Chl *a* (15.15 mg g<sup>-1</sup> FM) was obtained when they were subjected to ECw of 0.7 dS m<sup>-1</sup>, with reduction in this variable from this salinity level, and the lowest Chl *a* content (6.354 mg g<sup>-1</sup> FM) was found in plants irrigated using water with salinity of 3.5 dS m<sup>-1</sup>. On the other hand, when passion fruit plants were grown under a dose of K<sub>2</sub>O of 100%, the highest Chl *a* content (16.166 mg g<sup>-1</sup> FM) was observed under ECw of 0.3 dS m<sup>-1</sup>, and the minimum estimated value (5.124 mg g<sup>-1</sup> FM) was observed in those receiving the highest salinity level (3.5 dS m<sup>-1</sup>). The deleterious effect on chlorophyll *a* synthesis was more pronounced when the K<sub>2</sub>O dose increased, reinforcing the saline character of the fertilizer and the excess of salts in the water.

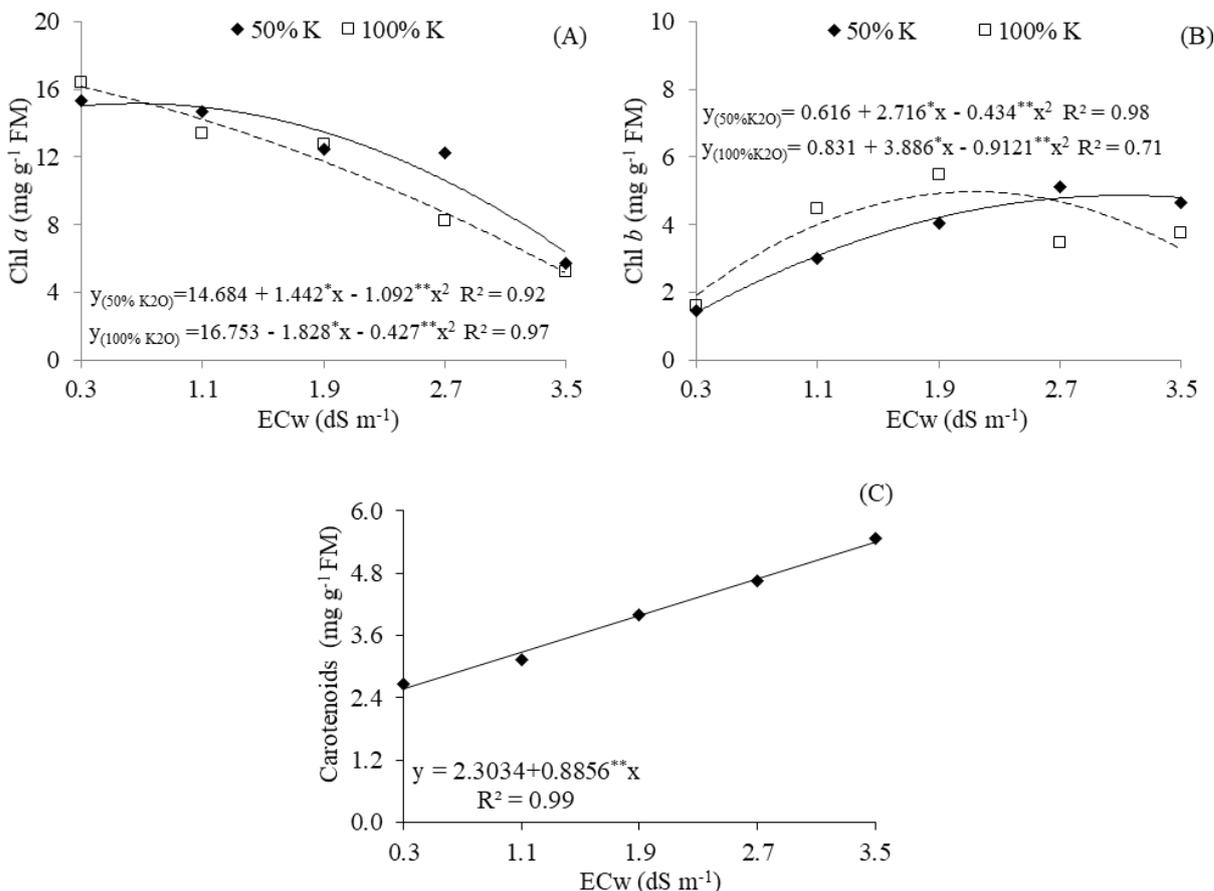
The reduction in chlorophyll *a* content in passion fruit plants may be related to the oxidative stress caused by reactive oxygen species in the

metabolism, due to the photo-oxidation of pigments, associated with the degradation of chlorophyll molecules (SILVA et al., 2016). In addition, salt stress stimulates the enzymatic activity of chlorophyllase, which degrades the molecules of the photosynthesizing pigment and induces the structural destruction of chloroplasts, also causing imbalance and loss of activity of pigmentation proteins (MUNNS; TESTER, 2008). Cavalcante et al. (2011) in a study aimed at determining the effects of different electrical conductivities of irrigation water (ECw from 0.5 to 4.5 dS m<sup>-1</sup>) on the contents of photosynthetic pigments, found that the increase in the salt concentration of irrigation water reduced the chlorophyll *a* synthesis of passion fruit.

The chlorophyll *b* content of passion fruit was also significantly influenced by the interaction between salinity levels and potassium doses. According to the regression equations (Figure 4B), the quadratic model fitted best to the data. When the K<sub>2</sub>O dose of 50% was used, the highest Chl *b* content (4.80 mg g<sup>-1</sup> FM) was obtained in plants under irrigation with ECw of 3.5 dS m<sup>-1</sup>. In plants subjected to the K<sub>2</sub>O dose of 100%, the maximum estimated value was 4.969 mg g<sup>-1</sup> FM, obtained

under water salinity of 2.1 dS m<sup>-1</sup>. The increase in chlorophyll *b* biosynthesis by plants under salt stress conditions is an adaptive response, as this pigment helps broaden the light absorption range and transfers it to chlorophyll *a*, which effectively acts on the photochemical reactions of photosynthesis, making light capture more efficient (LIMA et al.,

2011). Lima et al. (2018) in a study evaluating the effects of salt stress (EC<sub>w</sub> of 0.8 and 3.8 dS m<sup>-1</sup>) on the photosynthetic pigments of West Indian cherry, concluded that irrigation with high-salinity water stimulates the biosynthesis of chlorophyll *b* and carotenoids.



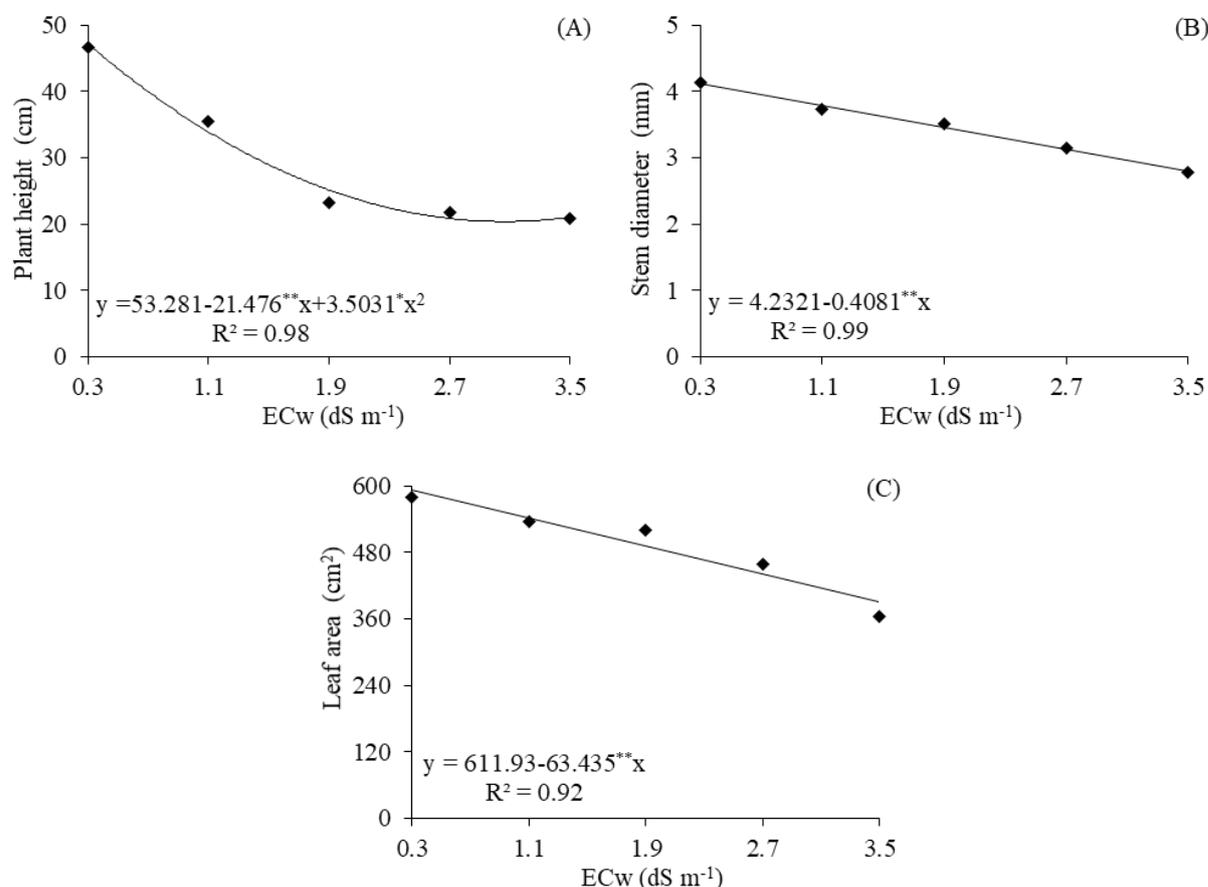
**Figure 4.** Contents of chlorophyll *a* - Chl *a* (A) and chlorophyll - Chl *b* (B) as a function of the interaction between water salinity levels – EC<sub>w</sub> and potassium doses, and content of carotenoids – Car (C) of ‘BRS Rubi do Cerrado’ passion fruit plants as a function of irrigation water salinity – EC<sub>w</sub>, at 40 days after sowing.

The carotenoid content of passion fruit plants increased linearly with irrigation water salinity, at 40 DAS and, according to the regression equation (Figure 4C), there was an increase of 38.44% per unit increment in EC<sub>w</sub>, that is, the synthesis of carotenoids in plants irrigated with EC<sub>w</sub> of 3.5 dS m<sup>-1</sup> increased by 2.83 mg g<sup>-1</sup> FM in comparison to those under water salinity of 0.3 dS m<sup>-1</sup>. The increase in carotenoid biosynthesis by passion fruit plants stands out as a strategy to protect the antenna complex, since they act as reducing agents and protect pigments from oxidative reactions (MELO; SOUZA; CUNHA, 2017). Unlike the results obtained in the present study, Freire and Nascimento (2018), when determining the effects of irrigation with low-salinity (0.5 dS m<sup>-1</sup>) and high-salinity (4.5 dS m<sup>-1</sup>) water on the contents of photosynthesizing pigments in yellow passion fruit, found that the lowest carotenoid contents were obtained in plants irrigated with 4.5 dS m<sup>-1</sup> water.

Passion fruit plant height was negatively affected by the increase in the levels of water electrical conductivity. According to the regression equation (Figure 5A), the highest growth in PH was observed in plants subjected to EC<sub>w</sub> of 0.3 dS m<sup>-1</sup> (47.15 cm). Plants grown under water salinity of 3.5 dS m<sup>-1</sup> had the largest reduction in PH, equal to 26.126 cm compared to those under irrigation using water with the lowest salinity level (0.3 dS m<sup>-1</sup>). The reduction in the height of passion fruit plants as a function of the increase in water salinity may be related to the reduction in the soil matric potential, which causes restriction in water absorption by plants. In addition, the increase of osmotic pressure in the soil may reach values at which plants will not have sufficient suction forces to overcome soil potential, and the consequence of such increase in the salinity of the soil solution is the reduction in water availability and absorption, reducing cell division and elongation, resulting in decrease of

growth in plant height (GRACIANO et al., 2011). Evaluating the growth of two passion fruit cultivars (yellow and purple) as a function of irrigation with waters of different salinities, Freire and Nascimento

(2018) concluded that the height of passion fruit plants, regardless of genotype, was negatively affected by irrigation with high-salinity water ( $3.5 \text{ dS m}^{-1}$ ).



**Figure 5.** Plant height (A), stem diameter (B) and leaf area (C) of ‘BRS Rubi do Cerrado’ passion fruit plants as a function of irrigation water salinity - ECw (A) and potassium doses (B), at 40 days after sowing.

The stem diameter of passion fruit plants decreased linearly in response to increasing levels of water salinity. According to the regression equation (Figure 5B), there were reductions of 9.64% per unit increment in ECw, i.e., a reduction of 31.77% (1.305 mm) in the SD of plants irrigated with  $3.5 \text{ dS m}^{-1}$  water, compared to those subjected to  $0.3 \text{ dS m}^{-1}$ . The inhibition of growth in stem diameter is a result of the changes that occurred in stomatal conductance (Figure 1A), transpiration (Figure 1B) and  $\text{CO}_2$  assimilation rate due to the reduction in the rate of water absorption by plants. According to Bezerra et al. (2016) under salt stress conditions, plants undergo inhibition of growth, due to the water deficit caused by excess soluble salts in the root zone, which leads to a reduction in cell turgor, consequently reducing cell expansion and reducing plant growth. Cavalcante et al. (2009), when evaluating the initial growth of yellow passion fruit seedlings subjected to water salinity levels (ECw:  $0.4$  to and  $4.0 \text{ dS m}^{-1}$ ), concluded that the increase in the electrical conductivity of irrigation water significantly increased the saline character of the

substrates, resulting in reduction of growth in stem diameter, at 60 days after sowing.

It can be observed in Figure 5C that the increase in irrigation water salinity resulted in reduction in the LA of passion fruit plants, at 40 DAS, a decrease of 10.36% per unit increase in ECw. According to the regression equation (Figure 5C), when plants were subjected to irrigation with  $3.5 \text{ dS m}^{-1}$  water, their LA decreased by  $44.404 \text{ cm}^2$  in comparison to those under electrical conductivity of  $0.3 \text{ dS m}^{-1}$ . Inhibition of leaf expansion in plants, caused by salt stress, is associated with a decrease in the osmotic potential of the soil solution and its restriction on water and nutrient flow in the soil-plant-atmosphere direction, causing morphological and anatomical changes in the plant (BEZERRA et al., 2018). Reduction in leaf area stands out as a mechanism of tolerance of plants to salt stress and an alternative to maintain cell turgor, reducing water losses by transpiration and, consequently, reducing the transport of toxic ions such as  $\text{Na}^+$  and  $\text{Cl}^-$  in the xylem (OLIVEIRA et al., 2011). Studies conducted with soursop (VELOSO et al., 2019) and guava

(BEZERRA et al., 2018) have also reported that the increase in water salinity caused reduction in leaf area.

## CONCLUSIONS

Water salinity from 0.3 dS m<sup>-1</sup> reduces stomatal opening, transpiration, CO<sub>2</sub> assimilation and inhibits the growth of 'BRS Rubi do Cerrado' passion fruit plants, at 40 days after sowing.

Reduction in the instantaneous carboxylation efficiency of passion fruit is related to the action of non-stomatal factors, as there is no CO<sub>2</sub> restriction in the substomatal cavity.

The dose of 150 mg K<sub>2</sub>O kg<sup>-1</sup> of soil, corresponding to 100%, intensifies the effect of salt stress on the assimilation rate and the instantaneous carboxylation efficiency of 'BRS Rubi do Cerrado' passion fruit.

There is interaction between water salinity levels and potassium doses for chlorophyll *a* and *b* contents in 'BRS Rubi do Cerrado' passion fruit.

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