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Saline water irrigation strategies and potassium fertilization on physiology and fruit production of yellow passion fruit[1]

Estratégias de irrigação com água salina e adubação potássica na fisiologia e produção do maracujazeiro amarelo

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HIGHLIGHTS:

The yellow passion fruit 'BRS GA1' is sensitive to salt stress in the successive vegetative/flowering and flowering stages.
In the vegetative/flowering and vegetative/fruiting stages, salt stress reduces leaf water potential drastically.
The current K fertilizer recommendation for 'BRS GA1' yellow passion fruit is considered excessive.

ABSTRACT: The objective of this study was to evaluate the effects of saline water irrigation management strategies and potassium doses on the concentration of photosynthetic pigments, gas exchange, and fruit production of 'BRS GA1' yellow passion fruit. The experiment was carried out under field conditions using a randomized block design, with treatments based on a 6 × 2 factorial scheme, related to six management strategies for irrigation with saline water (irrigation with low-salinity water throughout the crop cycle-WS; irrigation with high-salinity water in the vegetative stage-VE; flowering stage-FL; fruiting stage-FR; and successively in vegetative/flowering stages-VE/FL and vegetative/fruiting stages-VE/FR) and two doses of potassium (60 and 100% of the recommendation), with four replicates. The dose of 100% recommendation corresponded to 345 g of K_2O plant^{-1} year^{-1}. High electrical conductivity irrigation water (4.0 dS m^{-1}) was used in different phenological stages according to treatment, alternating with water of low electrical conductivity (1.3 dS m^{-1}). The synthesis of chlorophyll a and b, stomatal conductance, instantaneous carboxylation efficiency and water use efficiency of 'BRS GA1' yellow passion fruit were reduced under irrigation with water of 4.0 dS m^{-1} in all strategies adopted. Fertilization with 60% of the K recommendation promoted greater number of fruits and yellow passion fruit yield. Irrigation with 4.0 dS m^{-1} water in the vegetative/flowering and flowering stages reduced the yield of yellow passion fruit.

Key words: *Passiflora edulis* Sims, salt stress, osmoregulation

RESUMO: Objetivou-se com este estudo avaliar os efeitos das estratégias de manejo da irrigação com água salina e doses de potássio sobre os teores de pigmentos fotossintéticos, as trocas gasosas, e a produção de maracujazeiro amarelo 'BRS GA1'. A pesquisa foi desenvolvida sob condições de campo, utilizando-se o delineamento de blocos casualizados, com tratamentos formados a partir de um esquema fatorial 6 × 2, relativos a seis estratégias de manejo da irrigação com água salina (irrigação com água de baixa salinidade durante todo ciclo de cultivo-SE; irrigação com água de alta salinidade na fase vegetativa-VE; de floração-FL; de frutificação-FR; nas fases sucessivas vegetativa/floração-VE/FL e vegetativa/frutificação -VE/FR) e duas doses de potássio (60 e 100% de K_2O da recomendação), com quatro repetições. A dose de 100% da recommendação correspondeu a 345 g de K_2O planta^{-1} ano^{-1}. Utilizaram-se água com elevada condutividade elétrica (4,0 dS m^{-1}) em diferentes fases fenológicas conforme tratamento, intercalada com água de baixa condutividade elétrica (1,3 dS m^{-1}). A síntese de clorofila a e b, a condutância estomática, a eficiência instantânea de carboxilação e a eficiência no uso da água de maracujazeiro amarelo 'BRS GA1' foram reduzidas com irrigação com água de 4,0 dS m^{-1} em todas as estratégias adotadas. A adubação com 60% da recomendação de K promoveu maior número de frutos e produtividade do maracujazeiro amarelo. A irrigação com água de 4,0 dS m^{-1} nas fases vegetativa/floração e de floração reduziu a produtividade do maracujazeiro amarelo.

Palavras-chave: *Passiflora edulis* Sims, estresse salino, osmorregulação

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Introduction

Yellow passion fruit has stood out among the fruit crops of economic importance in Brazil, due to the physicochemical quality of its fruits and acceptance by the Brazilian consumers (Santos et al., 2014), is destined for fresh consumption and industry in the preparation of various products, especially carbonated and mixed beverages, syrups, jellies, dairy products, ice cream, and canned foods (Santos et al., 2017).

In the semiarid region of Northeast Brazil, due to climatic adversities, the production of yellow passion fruit is conditioned on irrigation management. However, the water used in irrigation commonly has high concentrations of salts, both in surface and underground water found in dams and wells (Silva et al., 2014). High salt concentration reduces the osmotic potential of the soil solution and induces the plant to close its stomata to prevent the loss of water to the atmosphere, limiting transpiration and the photosynthetic rates (Andrade et al., 2019).

In passion fruit, salt stress decreases leaf osmotic potential, increases intercellular leakage and inhibits photosynthetic pigment synthesis due to the action of the enzyme chlorophyllase and structural destruction of chloroplasts (Cavalcante et al., 2011; Lima et al., 2020a). Among the alternatives used to reduce the effects of salt stress in plants, the application of saline water in the phenological stages of greater tolerance stands out, along with the period and time of exposure of plants to the salts.

Potassium fertilization can also mitigate the deleterious effects of salt stress on plants. Potassium is the second most required nutrient by passion fruit (Silva Júnior et al., 2013). It is involved in translocation and maintenance of water balance and participates in various biochemical and physiological functions, such as stomatal movement, enzymatic activation, protein synthesis, photosynthesis, osmoregulation and reduction of excessive absorption of ions such as Na^+ (Ahanger et al., 2017).

In this context, the objective of this study was to evaluate the effects of saline water irrigation management strategies and potassium doses on the concentration of photosynthetic pigments, gas exchange, and fruit production of 'BRS GA1' yellow passion fruit.

Material and Methods

The experiment was carried out from August 2019 to May 2020 in a field at the experimental farm, belonging to the Center of Science and Agri-Food Technology-CCTA of the Federal University of Campina Grande-UFCG, located in the municipality of São Domingos, Paraíba, Brazil, at the coordinates: 06° 48' 50" S latitude and 37° 56' 31" W longitude, at an altitude of 190 m. The data of average maximum and minimum air temperatures, precipitation, and relative air humidity are shown in Figure 1.

The treatments were distributed in randomized blocks in a 6 × 2 factorial scheme, corresponding to saline water irrigation management strategies (IMS) (irrigation with low electrical conductivity water throughout the cultivation cycle (without stress-WS); irrigation with high-salinity water in the vegetative-VE; flowering-FL; fruiting-FR; and successively in the vegetative/flowering-VE/FL and vegetative/fruiting-VE/FR stages) and two doses of potassium (60 and 100% of K_2O recommendation of Costa et al. (2008), with four replicates, totaling 48 experimental units, and each plot consisted of four plants. The potassium dose of 100% corresponded to 345 g of K_2O plant^{-1} year^{-1}. The saline water irrigation management strategies were established using two levels of electrical conductivity of irrigation water (ECw), one of low salinity

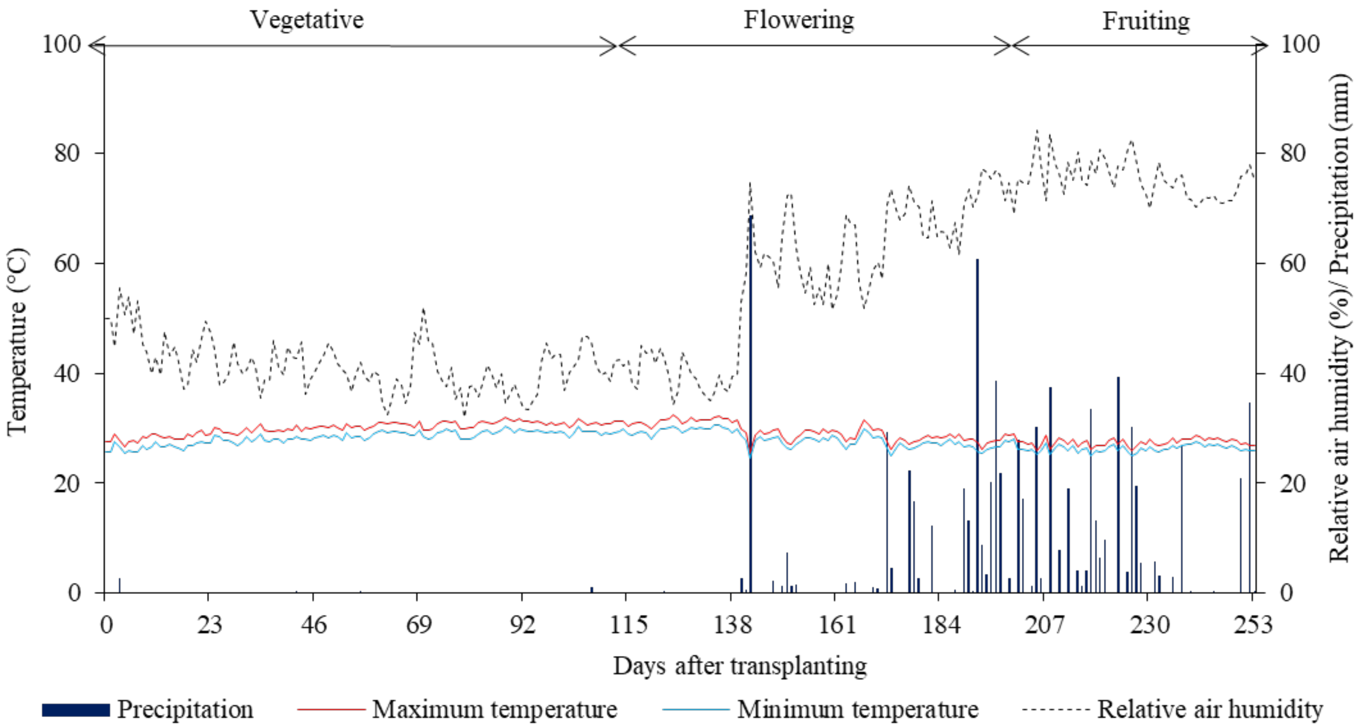


Figure 1. Data of maximum and minimum average air temperature, precipitation, and relative air humidity during the experimental period

(1.3 dS m^{-1}) and the other of high salinity (4.0 dS m^{-1}), in the following stages of crop growth: irrigation with low-salinity water throughout the cultivation cycle-WS (1-253 days after transplanting-DAT) and irrigation with high-salinity water in the stages VE-from transplanting to the emergence of the floral primordium (50-113 DAT); FL-from emergence of the floral primordium to the full development of the floral bud (anthesis) (114-198 DAT); FR-from fertilization of the floral bud to the appearance of fruits with yellow spots (199-253 DAT); VE/FL-in the vegetative and flowering stages (50-198 DAT); and VE/FR-in the vegetative and fruiting stages (50-113 and 199-253 DAT). ECw values were defined as a function of the quality of well water available at the CCTA/UFCG experimental area, which has the lowest electrical conductivity of 1.3 dS m^{-1}. The highest value (4.0 dS m^{-1}) was defined based on research results reported by Lima et al. (2020b).

Seeds of ‘BRS GA1’ yellow passion fruit were used in the experiment. For seedling formation, two seeds were sown in plastic bags with dimensions of 15 × 20 cm, filled with substrate, consisting of 84% Entisol of the experimental area, 15% autoclaved sand and 1% aged bovine manure. After the seedlings emerged, thinning was performed, leaving only one plant per bag. During the seedling formation period, low-salinity water (ECw = 1.3 dS m^{-1}) was used in irrigation. At 61 days after sowing (DAS), the seedlings were transplanted to the area in the field. The management of irrigation with high-salinity water (ECw 4.0 dS m^{-1}) started at 50 DAT when the main branch reached the height of the supporting wire.

In the preparation of the soil, one plowing operation was performed, followed by harrowing, aiming at breaking 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, a composite soil sample of the 0-0.40 m layer was collected and characterized with respect to its chemical and physical properties according to the methodologies proposed by Teixeira et al. (2017): Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, H^{+}+Al^{3+} = 2.44; 1.81; 0.81; 0.30; and 0 $cmol_c$ kg^{-1}, respectively; Exchangeable sodium percentage = 15.11%; Organic matter = 0.81 dag kg^{-1}; P = 10.60 mg kg^{-1}; electrical conductivity of the saturation extract = 1.52 dS m^{-1}; and pH in water (1:2.5) = 7.82; sand, silt and clay = 820.90; 170.10 and 9.00 g kg^{-1}, respectively; Apparent and particle density = 1.23 and 2.72 kg dm^{-3}, respectively.

The dimensions of the planting pit were 0.40 × 0.40 × 0.40 m. After opening the pit, fertilization was performed using 20 L of well decomposed bovine manure and 50 g of single superphosphate (17% P_2O_5), as recommended by Costa et al. (2008). Nitrogen and potassium fertilization was performed monthly, using urea (45% N) and potassium chloride (60% K_2O) as sources of nitrogen and potassium, respectively. In the crop formation stage, 65 g of N $plant^{-1}$ were applied and, in the flowering and fruiting stages, 160 g of N $plant^{-1}$ were applied. In case of the 100% potassium dose, 65 g of K_2O $plant^{-1}$ were applied in the crop formation stage (vegetative stage) and 280 g of K_2O $plant^{-1}$ were applied in the flowering and fruiting stages.

Micronutrient application was performed fortnightly using the 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%; EDTA chelating agent = 70%) at a concentration of 1 g L^{-1}, by foliar spraying.

The spacing used was 3 m between rows and 3 m between plants, using the trellis system with smooth wire n° 14 at the height of 2.0 m. This trellis system gave support to the yellow passion fruit plants, which were guided using a string. When the plants reached 0.10 m above the trellis, the apical bud was pruned, aiming at the production of two secondary branches, guided to each side up to the length of 1.10 m. After the secondary branches reached such length, a new pruning was performed on their apical bud, aiming at the production of the tertiary branches, which were trained to come down up to 0.30 m from the soil. During the experiment, tendrils and unwanted branches were eliminated to favor the development of the plant.

The irrigation water of the treatment with the low value of electrical conductivity (1.3 dS m^{-1}) came from an artesian well located in the experimental area of CCTA/UFCG; the water with an ECw level of 4.0 dS m^{-1} was prepared by the dissolution of iodine-free NaCl in the well water (ECw of 1.3 dS m^{-1}) considering the relationship between ECw and salt concentration (Richards, 1954) according to the equation: mg L^{-1} = 640 × ECw (dS m^{-1}).

Irrigation was carried out by a localized drip system, using 32-mm-diameter PVC tubes in the mainline and 16-mm-diameter low-density polyethylene tubes in the lateral lines using drippers with a discharge rate of 10 L h^{-1}. Each plant had two pressure-compensating drippers (GA 10 Grapa model), each one at a 0.15 m distance from the stem. The plants were irrigated daily, at 7 a.m., according to the adopted strategy, and the water depth applied was estimated based on the crop evapotranspiration (ETc - mm day^{-1}), according to Bernardo et al. (2013), obtained by Eq. 1:

$$ETc = ETo \cdot Kc \quad (1)$$

where:

ETo - reference evapotranspiration of Penman-Monteith, mm day^{-1}; and,

Kc - crop coefficient, dimensionless.

ETo was estimated daily from climatic data collected at the São Gonçalo Meteorological Station, located in the municipality of Sousa - PB. The crop coefficients of 0.4 (50-113 DAT), 0.8 (114-198 DAT) and 1.2 (199-253 DAT) were used, according to the recommendation contained in Nunes et al. (2017).

During the experiment, all cultural practices and phytosanitary treatments recommended for the crop were carried out. To prevent the appearance of fungi, Ridomil gold MZ® (250g 100 L^{-1}) was applied. In addition to this fungicide, the acaricide/fungicide Dithane® (350 g 100 L^{-1}) was also applied. For pest control, Decis 25 EC® (30 mL 100 L^{-1}) and Lannate® (100 mL 100 L^{-1}) were used. Weed control whenever necessary was carried out by manual weeding.

At 239 days after transplanting (when the plants were in the fruiting stage), the following variables were evaluated: leaf water potential (Ψ_w), percentage of intercellular electrolyte leakage (% IEL), the concentration of photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) and gas exchange. Ψ_w was measured with a Scholander pressure chamber on the leaf (between the 3rd and 5th position from the apex) with good phytosanitary condition. To take the measurement, the chamber was pressurized with compressed gas until the exudation of liquid through the xylem.

The percentage of intercellular electrolyte leakage was obtained as recommended by Sousa et al. (2017). Chlorophyll a and b, and carotenoid concentrations were quantified by spectrophotometer, respectively by determining absorbance (ABS) at wavelengths of 470, 646, and 663 nm, according to the methodology described by Lima et al. (2020a). The values obtained for chlorophyll a, chlorophyll b, and carotenoid concentrations in the leaves were expressed in mg g^{-1} of fresh matter (FM).

Gas exchange was measured by stomatal conductance (gs), transpiration (E), CO_2 assimilation rate (A) and internal CO_2 concentration (Ci), evaluated on the third leaf counted from the apex of the fruit-bearing branches. These data were then used to calculate the instantaneous water use efficiency (WUEi) (A/E) and the instantaneous carboxylation efficiency (CEi). The readings were taken between 6.30 and 10:00 a.m., conducted under natural conditions of air temperature, CO_2 concentration, and using an artificial radiation source of 1.200 μmol m^{-2} s^{-1}.

The number of fruits per plant (NF) was obtained during harvesting from 199 to 253 DAT, by counting. Harvesting was carried out when the fruits changed their skin color from green to partially yellow and before detaching from the plant. At the time of harvest, the fruits were weighed and packed in boxes and separated by paper, which also lined the boxes, to avoid friction and mechanical damage to them. Fruit yield (t ha^{-1}) was obtained by multiplying the average fruit production per plant by the number of plants per hectare.

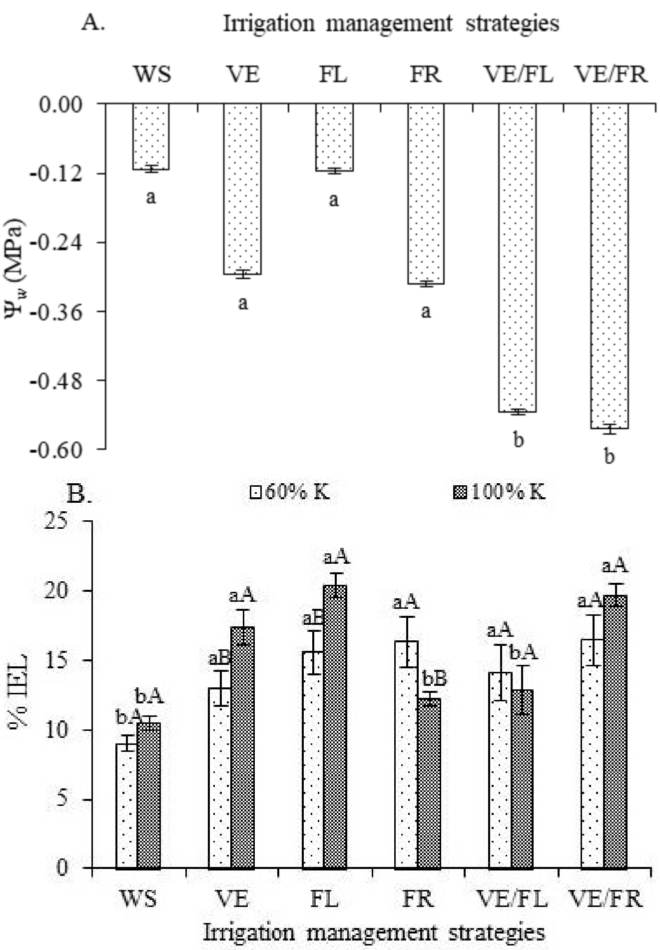
The data obtained were evaluated by analysis of variance after the normality and homogeneity test of the data (Shapiro-Wilk test). The Scott-Knott test ($p \leq 0.05$) was used for the saline water irrigation management strategies and F test ($p \leq 0.05$) for potassium doses, using the statistical program SISVAR.

Results and Discussion

The analysis of variance indicated significant effects of saline water irrigation management strategies (IMS) on water potential (Ψ_w), percentage of intercellular electrolyte leakage (% IEL), chlorophyll a (Chl a), chlorophyll b (Chl b), and carotenoids (Car) of 'BRS GA1' yellow passion fruit. Potassium doses (KD) had a significant influence only on % IEL. The interaction between IMS and KD significantly affected the % IEL, Chl a, and Chl b of yellow passion fruit.

The leaf water potential (Ψ_w) of 'BRS GA1' yellow passion fruit plants (Figure 2A) irrigated with high-salinity water (4.0 dS m^{-1}) in the VE/FL and VE/FR stages was significantly reduced compared to those subjected to the other strategies, which did not differ significantly. The reduction in Ψ_w in plants subjected to VE/FL and VE/FR strategies is a consequence of the decrease in water flow from the roots to aerial parts, due to the reduction of the Ψ_w of the soil solution.

The decrease in Ψ_w also causes the loss of cell turgor, inducing stomatal closure in plants (Cruz et al., 2018).



In Figure A, means with the same letters indicate no significant differences between saline water irrigation management strategies (Scott-Knott test, $p \leq 0.05$). In Figure B, means with the same uppercase letters indicate no significant differences between potassium doses in the same irrigation management strategy by F test at $p \leq 0.05$, and same lowercase letter in the same potassium dose indicate no significant difference between saline irrigation management strategies (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error (n = 4). 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 (50-113/199-253 DAS).

Figure 2. Water potential - Ψ_w (A) of 'BRS GA1' yellow passion fruit plants as a function of different saline water irrigation management strategies and percentage of intercellular electrolyte leakage - % IEL as a function of the interaction between saline water irrigation management strategies and potassium doses (B) at 239 days after transplanting

According to Negrão et al. (2017), salt-tolerant plants decrease the hydraulic conductance of their roots, thus reducing the absorption of water with excess salts and, therefore, causing a decrease in the water potential of their leaves.

The percentage of intercellular electrolyte leakage of yellow passion fruit fertilized with 60% of the K recommendation was statistically higher than that of plants that received the 100% K dose and were irrigated with high-salinity water in the FR stage (Figure 2B). When comparing the % IEL values of plants subjected to the WS, VE/FL and VE/FR strategies, there was no significant difference among them regarding K doses. In general, regardless of the K dose, the lowest % IEL was observed in plants grown under the low level of water salinity (WS). The plasma membrane is the part of the cell that first confronts the deleterious effect of salt stress and, for plant survival, it must be less susceptible and maintain its integrity under conditions of high concentration of salts to fulfill its selective function, regulating the passage of water, ions, metabolites and electrochemical potential (Carrasco-Ríos & Pinto, 2014).

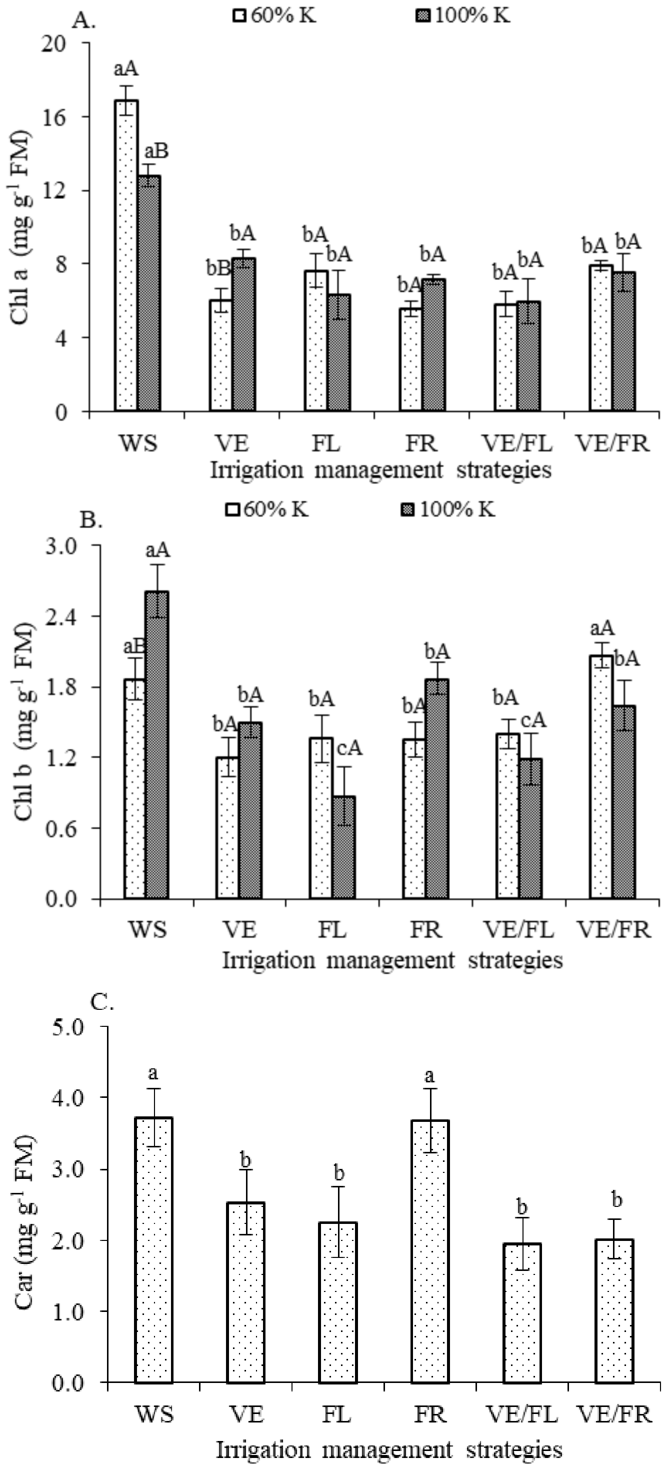
In the follow-up analysis of the interaction between K doses and saline water irrigation management strategies for % IEL (Figure 2B), it can be verified that in plants that received 60% of the K recommendation, the highest % IEL was observed when the water of high ECw was used in the FR stage and it did not differ statistically from others, except for WS. However, when yellow passion fruit was fertilized with 100% of the recommendation, there was an increase in % IEL under the VE, FL and VE/FR strategies. In a study evaluating the intercellular electrolyte leakage and citrus scion-rootstock combinations as a function of irrigation with waters of different salinities (ECw ranging from 0.6 to 3.0 dS m^{-1}), Sousa et al. (2017) observed a linear increase in % IEL regardless of the genotype studied, attributing it to the greater fluidity of the membrane due to injuries caused by salt stress.

The chlorophyll a concentrations of yellow passion fruit decreased significantly as a function of saline water irrigation management strategies (Figure 3A). Plants irrigated with high-salinity water in the VE, FL, FR, VE/FL, and VE/FR stages significantly decreased their Chl a concentrations, regardless of the K dose applied compared to plants subjected to irrigation with low-salinity water (WS). The highest synthesis of Chl a and the highest value was obtained in plants irrigated with low-salinity water under the K dose corresponding to 60% of the recommendation. However, the relative decrease in Chl a in plants that received water with ECw of 4.0 dS m^{-1} was lower compared to when they were fertilized with 100% of the K dose (Figure 3A). The potassium source used in this study is a factor that may have contributed to the inhibition of carotenoid synthesis by yellow passion fruit. Potassium chloride is a fertilizer that has a high salt index (116.3) and, when associated with high water salinity (4.0 dS m^{-1}), it decreases the osmotic potential of the soil solution, restricting the absorption of water and nutrients.

The decrease in Chl a concentrations induced by salt stress is indicative of the destruction of the thylakoid membrane structure, reducing the affinity between chlorophylls and chloroplast proteins (Sayyad-Amin et al., 2016), and of increase in the activity of chlorophyllase, which degrades the molecules of the photosynthesizing pigment, also causing the imbalance and loss of activity of pigmentation proteins (Cavalcante et al., 2011).

Results found in this study are similar to those observed by Lima et al. (2020a), who evaluated the photosynthetic pigments of 'BRS Rubi do Cerrado' yellow passion fruit in the seedling formation stage, as a function of irrigation with saline water (ECw from 0.3 to 3.5 dS m^{-1}) and potassium fertilization, and observed that the deleterious effect on chlorophyll a synthesis was more pronounced when the K dose increased, reinforcing the saline character of the fertilizer and the excess of salts in the water.

The interaction between the factors (IMS × KD) also significantly affected the chlorophyll b concentration of yellow passion fruit (Figure 3B). Plants fertilized with 100% of the K recommendation and subjected to the WS strategy obtained



In Figures A and B, means with the same uppercase letters indicate no significant differences between potassium doses in the same irrigation management strategy by F test at $p \leq 0.05$, and same lowercase letter in the same potassium dose indicate no significant difference between saline irrigation management strategies (Scott-Knott test, $p \leq 0.05$). In Figure C, means with the same letters indicate no significant differences between saline water irrigation management strategies (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error (n = 4). 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 (50-113/199-253 DAS).

Figure 3. Chlorophyll a - Chl a (A) and chlorophyll b - Chl b (B) concentrations of 'BRS GA1' yellow passion fruit plants as a function of the interaction between saline water irrigation management strategies and potassium doses, and carotenoid concentrations - Car (C) as a function of the different saline water irrigation management strategies, at 239 days after transplanting

chlorophyll b concentrations statistically higher than those observed in plants irrigated with water of high salinity in the other stages. It was observed that passion fruit plants irrigated with water of 4.0 dS m^{-1} in the FL and VE/FL stages significantly reduced their Chl b concentrations.

In the analysis of the interaction between K doses and saline water irrigation management strategies for Chl b concentrations (Figure 3B), it was noted that plants grown under ECw of 1.3 dS m^{-1} (WS) throughout the cycle and with high-salinity water in the VE/FR stages and fertilized with 60% of K stood out with the highest concentrations of Chl b. However, when the plants received 100% of the K recommendation under the strategies FL, VE/FL, and VE/FR, there was a reduction in Chl b concentrations, with the greatest reductions obtained under the FL and VE/FL stages. Water stress is usually characterized by chlorophyll loss, associated with a progressive decline in the photosynthetic capacity of plants (Pereira Filho et al., 2019).

The saline water management strategies significantly influenced the carotenoid concentrations of yellow passion fruit (Figure 3C). It was verified that plants subjected to the WS and FR strategies obtained a statistically higher carotenoid content compared to the plants that were irrigated with water of high salt concentration in the VE, FL, VE/FL, and VE/FR stages and there were no significant differences among them. Carotenoids have the potential to detoxify plants from the effects of ROS and function as collectors of light energy for photosynthesis. They act in the dissipation of excess energy through the xanthophyll cycle and can act as powerful stabilizers of the chloroplast membrane and the lipid phase of thylakoid membranes, reducing membrane fluidity and susceptibility to lipid peroxidation (Taibi et al., 2016).

Thus, the reduction in the synthesis of carotenoids in plants grown under the VE, FL, VE/FL, and VE/FR strategies may be the result of ß-carotene degradation and a reduction in zeaxanthin formation, causing a decrease in the biosynthesis of carotenoids, pigments involved in the protection against photoinhibition (Lima et al., 2004).

For the concentrations of photosynthetic pigments of 'BRS GA1' passion fruit (Figure 3), it is possible that the highest concentrations of chlorophyll b and carotenoids obtained in plants subjected to salt stress during the fruiting stage are related to the beneficial effects of the precipitations that occurred during this stage. It is noteworthy that the FR stage corresponded to the period of 199-253 DAT, that is, 54 days, and had 26 precipitation events totaling 413 mm, though distributed irregularly over time (Figure 1).

There was a significant effect of saline water irrigation management strategies on stomatal conductance (gs), CO_2 assimilation rate (A), instantaneous carboxylation efficiency (CEi), instantaneous water use efficiency (WUEi), number of fruits per plant (NF) and fruit yield (FY) of 'BRS GA1' yellow passion fruit. Potassium doses significantly influenced NF and FY. The interaction between IMS × KD significantly affected only the CO_2 assimilation rate and the number of fruits per plant of yellow passion fruit. The absence of a significant effect of potassium doses on the gas exchange of yellow passion fruit plants may be related to the 40 mm rainfall that occurred in the experimental area four days before the evaluation, which might have provoked leaching of this nutrient to depths beyond the root zone, further favored by the facts that potassium is poorly adsorbed by soil colloids and the fertilizer used (KCl) has high solubility (Duarte et al., 2013).

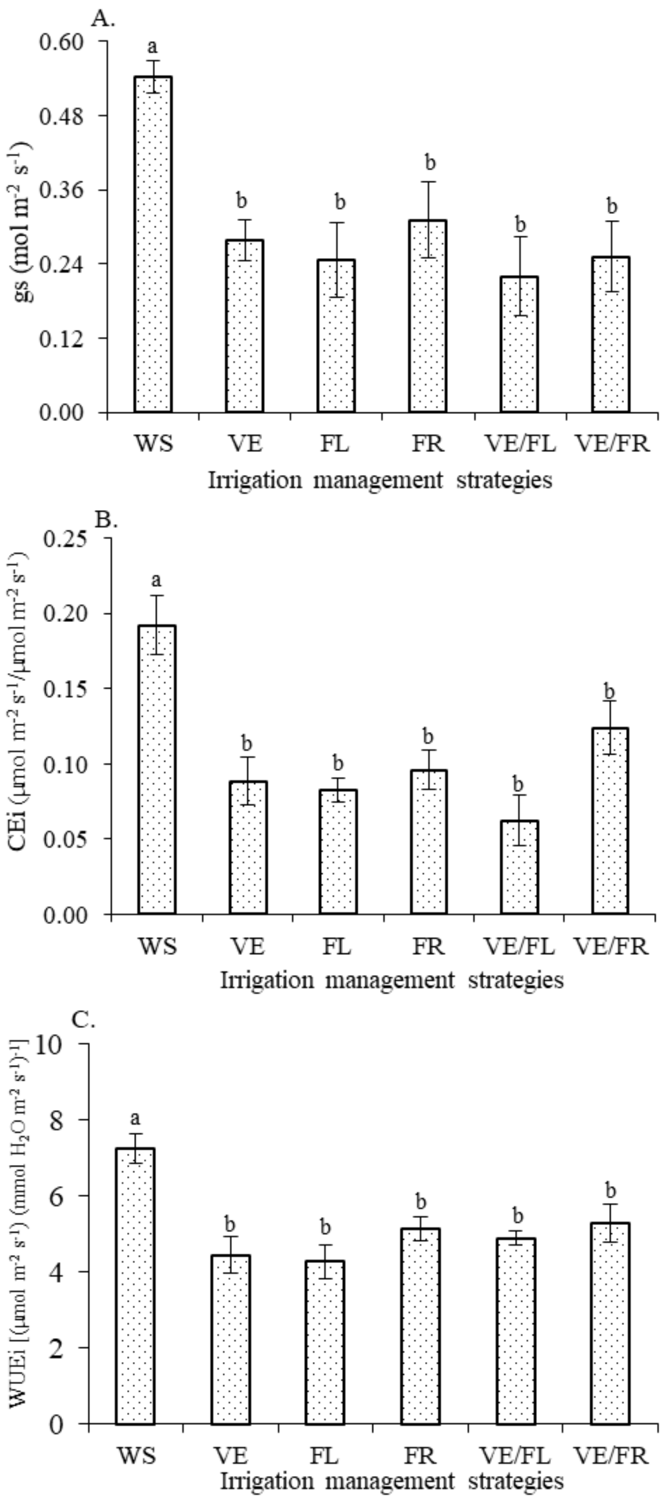
The stomatal conductance of yellow passion fruit (Figure 4A) subjected to irrigation with water of low level of electrical conductivity (WS) was statistically superior to that of plants cultivated under the other saline water irrigation management strategies, which had a similar effect on gs. The decrease in gs is a strategy of the plant to avoid excessive dehydration and can be considered a mechanism adopted by plants to adapt to salt stress conditions. Stomatal conductance (gs) in plants is mainly regulated by stomatal pore opening, stomatal density, and by the water transport capacity of the guard cells on the leaf surface. Thus, changes in gs occur due to changes in the water potential of the leaves (Ψ_w) or osmotic adjustment (Zhu et al., 2018).

The stomatal closure observed in this study through the reduction in stomatal conductance (Figure 4A) is a strategy used by plants to reduce the amount of water transpired, which can result in the reduction in the absorption and transport of toxic ions, such as Na^+ and Cl^-, to their interior, constituting another adaptive strategy (Pereira Filho et al., 2019). Silva et al. (2019), in a study evaluating the gas exchange of 'Guinezinho' passion fruit, as a function of irrigation with saline waters (ECw between 0.7 to 2.8 dS m^{-1}) during the seedling formation stage, observed that increase in the electrical conductivity of irrigation water from 0.7 dS m^{-1} negatively affected the stomatal conductance of the plants and highlighted that the stomatal closure restricts the entry of CO_2 into the leaf mesophyll cells, which may increase susceptibility to photochemical damage.

The instantaneous carboxylation efficiency of passion fruit plants was significantly influenced by the strategies of saline water use and, according to the means comparison test (Figure 4B), plants irrigated with low ECw (WS) during the entire cultivation cycle stood out with the highest CEi, being higher than the values observed in the other strategies. However, the use of high-salinity water negatively affected similarly the CEi of yellow passion fruit regardless of the strategy adopted.

Instantaneous carboxylation efficiency is a variable used to identify the action of non-stomatal factors that interfere in the CO_2 assimilation rate. Thus, the decrease in the CEi of plants may be related to an increase in photorespiration and decrease in ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO) activity due to the low availability of substrate (ATP and NADPH) for enzyme activation and regeneration, resulting from the accumulation of salts in leaf tissues, especially Na^+ and Cl^- (Dias et al., 2018), and with the action of other environmental factors favoring RuBisCO oxygenation and increase in the photorespiratory pathway, resulting in a significant decrease in carbon compounds (Voss et al., 2013). Reduction in CEi in plants grown under stress was also observed by Dias et al. (2018), in a study with 'BRS 366 Jaburu' West Indian cherry.

The instantaneous water use efficiency of the plants was also significantly affected by the saline water irrigation management strategies (Figure 4C). It is noted that plants cultivated with water of lower ECw during the entire cultivation cycle (WS) achieved a higher WUEi than those that were irrigated with high-salinity water in different phenological stages. When comparing the WUEi of the plants subjected to the other



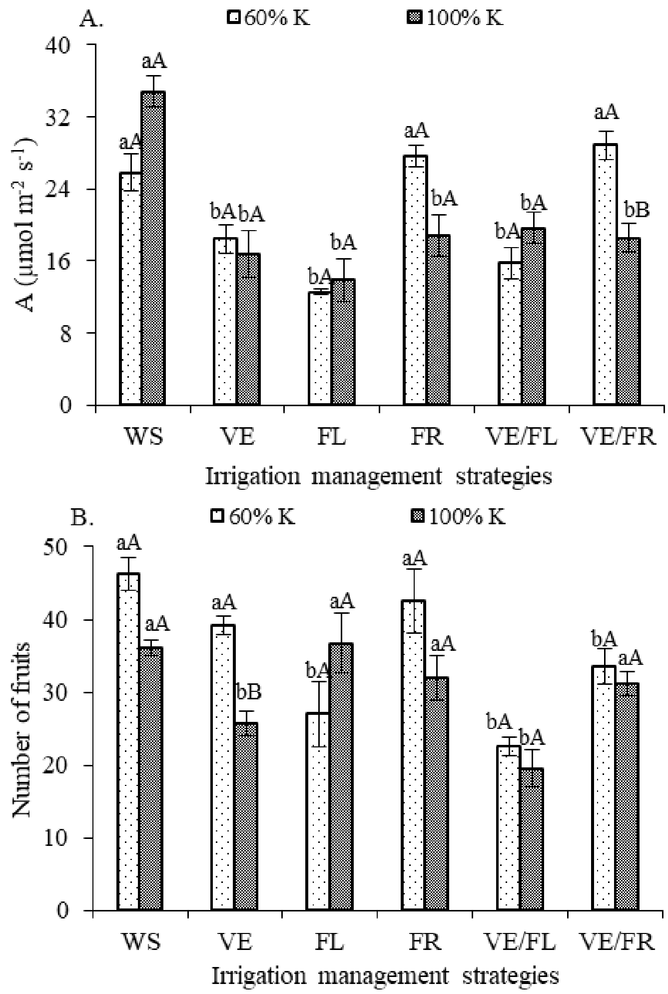
Means with the same letters indicate no significant differences between saline water irrigation management strategies (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error of the mean (n = 4). WS - irrigation with low-salinity water throughout the cultivation cycle (1-253 days 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 (50-113/199-253 DAS).

Figure 4. Stomatal conductance - gs (A), instantaneous carboxylation efficiency - CEi (B) and instantaneous water use efficiency - WUEi (C) of 'BRS GA1' yellow passion fruit as a function of saline water irrigation management strategies, at 239 days after transplanting

strategies, no significant differences were observed among them. It is worth pointing out that during the process of gas exchange, the absorption of carbon dioxide from the external environment occurs via stomata. This process also causes water loss and the plant in order to reduce this loss restricts the inflow of CO_2.

It is observed for gs, CEi, and WUEi (Figures 4A, B, and C) that, regardless of the irrigation management strategy, there was a reduction in these variables in comparison to the plants that received water with a lower level of salinity (WS). Although isolated precipitation events occurred during the FL and FR stages, there was no reduction in the impact of salt stress on 'BRS GA1' passion fruit plants. It is important to note that the gas exchange measurements reflect the water status of the plant at the time of the readings and that in the days before the assessment there was no precipitation in the experimental area (Figure 1). The precipitations that occurred during the FL and FR stages were 368 and 413 mm, respectively, distributed unevenly over 27 and 28 days.

The CO_2 assimilation rate of yellow passion fruit (Figure 5A) was significantly influenced by the interaction between



Means with the same uppercase letters indicate no significant differences between potassium doses in the same irrigation management strategy, by F test at $p \leq 0.05$, and same lowercase letter in the same potassium dose indicate no significant difference between saline water irrigation management strategies (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error of the mean (n = 4). 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 (50-113/199-253 DAS).

Figure 5. CO_2 assimilation rate - A (A) of 'BRS GA1' yellow passion fruit, at 239 days after transplanting, and number of fruits per plant (B) harvested as a function of saline water irrigation management strategies

IMS and KD. In plants fertilized with 60% of the K recommendation, the highest CO_2 assimilation rate was observed when the VE/FR strategy was used (28.86 μmol m^{-2} s^{-1}), statistically differing from those subjected to VE, FL, and VE/FL. On the other hand, it is verified that in plants fertilized with 100% of the K recommendation, the highest value of A (34.85 μmol m^{-2} s^{-1}) was obtained when the water of low electrical conductivity (1.3 dS m^{-1}) was used during the entire cultivation cycle (WS), without statistically differing from those that received 60% of KD. The decrease in the photosynthetic rate of plants induced by salt stress occurred due to stomatal and/or non-stomatal factors, causing changes in the metabolic processes of photosynthesis and adversely affecting the activities of a series of enzymes in the stroma involved in the reduction of CO_2 (Hnilicková et al., 2017). In addition, the reduction of photosynthesis can be a direct effect of the accumulation of Na^+ and Cl^- ions in leaf tissues.

As observed for photosynthetic pigments (Figure 3), the precipitations that occurred during the FR stage (Figure 1) may have alleviated the intensity of salt stress on plants. The highest A values observed in the FR and VE/FR stages are due to the period when it rained the most (413 mm). It is noteworthy that in the alternated strategy, that is, in VE/FR, precipitation was recorded only in the FR stage.

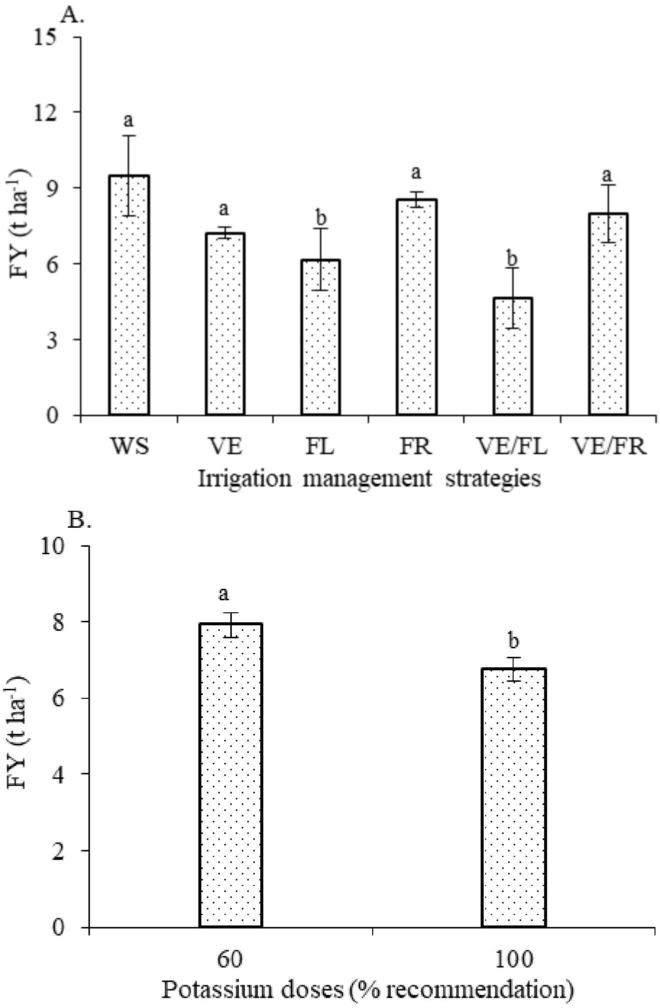
In the follow-up analysis of the interaction between K doses and saline water irrigation management strategies for the number of fruits harvested (Figure 5B), it is observed that plants fertilized with 60% of the K recommendation and subjected to irrigation with high-salinity water in the VE stages were statistically superior to those cultivated under 100% of KD. Although potassium is the second most required macronutrient by yellow passion fruit (Silva Júnior et al., 2013), high concentrations of this element in the soil solution may inhibit the absorption of Ca^{2+} and Mg^{2+} and can induce their deficiency in plants. Furthermore, deficient or excessive K fertilization can inhibit CO_2 assimilation by leaves and the transport of photoassimilates from leaves to roots (Trankner et al., 2018).

In plants grown under 100% of the K recommendation, the highest CO_2 assimilation rate was obtained when irrigation with low-salinity water was performed throughout the cultivation cycle (WS). It was verified that plants fertilized with 60% of the K recommendation (Figure 5B) and subjected to the VE, FR, and VE/FR strategies obtained a statistically higher number of fruits than plants subjected to irrigation with high-salinity water in the FL and VE/FL stages. In plants grown under 100% of the K recommendation, the highest NF was achieved in the FL strategy; however, there were no significant differences in comparison to those that received 60% of K recommendation.

Plants subjected to the VE, FL, FR, VE/FL, and VE/FR strategies had the lowest CO_2 assimilation rates and also had the lowest number of fruits (Figure 5A). It is worth highlighting that plants subjected to irrigation with high-salinity water in the VE/FL stages produced the lowest number of fruits regardless of the K dose. The greatest reduction in the number of fruits in plants irrigated with ECw of 4.0 dS m^{-1} in the VE/FL stages reflect the intensity and duration of exposure to the salts and may be related to the osmotic and/or ionic effect of Na^+ and Cl^-, changing the processes of absorption, transport, assimilation and distribution of nutrients in the plant.

The number of fruits in plants fertilized with 60% of the K recommendation was 13.5 fruits per plant more than those that received 100% of K recommendation and were irrigated with high-salinity water in the VE stage. In plants grown under the other strategies (WS, FL, FR, VE/FL and VE/FR), there were no significant differences when they were fertilized with doses of either 60 or 100% of the K recommendation. Dias et al. (2011), in a study evaluating the effects of irrigation waters with increasing salinity levels (ECw from 0.5 to 4.5 dS m^{-1}), on the fruit production of yellow passion fruit, concluded that the increase in ECw compromised the production capacity of the yellow passion fruit, in terms of number of fruits harvested and fruit production per plant.

The fruit yield of 'BRS GA1' yellow passion fruit plants (Figure 6A) subjected to the WS, VE, FR and VE/FR strategies (9.48; 7.22; 8.54 and 7.99 t ha^{-1}) was statistically higher



In Figure A, means with the same letters indicate no significant differences between saline water irrigation management strategies (Scott-Knott test, p ≤ 0.05). In Figure B, means with the same uppercase letters indicate no significant differences between potassium doses by F test at p ≤ 0.05. Vertical bars represent the standard error of the mean (n = 4). 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 (50-113/199-253 DAS).

Figure 6. Fruit yield (FY) of 'BRS GA1' yellow passion fruit as a function of irrigation management strategies with saline water (A) and potassium doses (B)

compared to those plants cultivated under irrigation with high salinity water in the FL and VE/FL stages. As observed for the number of fruits (Figure 5B), irrigation with ECw of 4.0 dS m^{-1} in the VE/FL stages continuously resulted in lower FY (4.63 t ha^{-1}), not differing significantly from the plants subjected to the FL strategy (6.16 t ha^{-1}).

Thus, it can be inferred that irrigation with high ECw in the vegetative/flowering or flowering stage is more harmful to the cultivation of yellow passion fruit, possibly because the development of the anther and the pollen grain are regulated by internal and external factors, which are highly sensitive to abiotic stresses such as salt stress.

Potassium doses significantly affected yellow passion fruit yield (Figure 6B). Plants cultivated under fertilization with 60% of the recommendation of Costa et al. (2008) showed a 15% higher yield (1.19 t ha^{-1}) compared to those fertilized with 100% K. The reduction in FY of passion fruit plants under 100% of the K_2O recommendation may be associated with the fertilizer source applied, as discussed earlier. Furthermore, when plants absorb K in quantity higher than necessary, this results in 'luxury consumption'. In the soil solution, the excess of potassium can interfere with the absorption of other elements, which compete for the same absorption sites, especially Ca^{2+} and Mg^{2+} (Trankner et al., 2018).

Conclusions

1. Fertilization with 100% of the K recommendation and use of irrigation water with electrical conductivity of 4.0 dS m^{-1} in the vegetative and flowering stages results in a higher percentage of intercellular electrolyte leakage in 'BRS GA1' passion fruit plants.
2. Concentration of chlorophylls a and b, stomatal conductance, instantaneous carboxylation efficiency and instantaneous water use efficiency of 'BRS GA1' yellow passion fruit are reduced when irrigated with water of electrical conductivity of 4.0 dS m^{-1} in all strategies adopted.
3. Fertilization with 60% of the K recommendation results in a higher number of fruits and fruit yield of yellow passion fruit.
4. Irrigation with high-salinity water successively in the vegetative/flowering and flowering stages reduces the yield of 'BRS GA1' yellow passion fruit.

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