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Original Article

Quantum yield, chlorophyll, and cell damage in yellow passion fruit under irrigation strategies with brackish water and potassium

Rendimento quântico, clorofila e dano celular em maracujazeiro-amarelo sob estratégias de irrigação com água salobra e potássio

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Abstract

The occurrence of water sources with high concentrations of salts in the semiarid region of Northeast Brazil stands out as a limiting factor in the cultivation of irrigated yellow passion fruit. Thus the search for irrigation strategies with brackish water is fundamental for the sustainability of irrigated crops. The objective of the present study was to determine the quantum yield, chlorophyll levels, and cell damage in yellow passion fruit cultivated under different irrigation strategies with brackish water and potassium fertilization. The experiment was conducted under field conditions in São Domingos - PB, Brazil, adopting a randomized block design in a 6×2 factorial scheme, consisting of six strategies of use of brackish water applied in the different phenological stages of crop and two doses of potassium (60 and 100% of the recommendation), with four replicates. Two levels of irrigation water salinity were used, with low (1.3 dS m^{-1}) and high electrical conductivity (4.0 dS m^{-1}). The potassium dose of 100% recommendation corresponds to the application of 345 g of K_2O per plant per year. The use of brackish water (4.0 dS m^{-1}) increased chlorophyll fluorescence and negatively affected the photosynthetic pigments of yellow passion fruit, regardless of the phenological stage. Salt stress intensified intercellular electrolyte leakage in passion fruit plants under higher dose of potassium. Our results show that fertilization equivalent to 100% of the potassium recommendation is excessive for yellow passion fruit 'BRS GA1' in the tropical semiarid region under salt stress conditions.

Keywords: *Passiflora edulis* Sims, salt stress, potassium fertilization, semiarid.

Resumo

A ocorrência de mananciais com altas concentrações de sais no semiárido nordestino destaca-se como fator limitante no cultivo do maracujazeiro-amarelo irrigado. Assim, a busca por estratégias de irrigação com água salobra é fundamental para a sustentabilidade da agricultura irrigada. O objetivo deste trabalho foi determinar o rendimento quântico, os teores de clorofila e dano celular em maracujazeiro-amarelo cultivado sob diferentes estratégias de irrigação com água salobra e adubação potássica. O experimento foi conduzido em condições de campo em São Domingos - PB, Brasil, adotando-se o delineamento em blocos casualizados em esquema fatorial 6×2, correspondendo a seis estratégias de uso de água salobra aplicadas nos diferentes estádios fenológicos da cultura e duas doses de potássio (60 e 100% da recomendação), com quatro repetições. Foram utilizados dois níveis de salinidade da água de irrigação, com baixa (1,3 dS m^{-1}) e alta condutividade elétrica (4,0 dS m^{-1}). A dose de potássio de 100% corresponde à aplicação de 345 g de K_2O por planta por ano. O uso de água salobra (4,0 dS m^{-1}) aumentou a fluorescência da clorofila e afetou negativamente os pigmentos fotossintéticos do maracujá-amarelo, independente do estádio fenológico. O estresse salino intensificou o extravasamento de eletrólitos em plantas de maracujazeiro adubadas sob alta dose de potássio. Os resultados mostram que a adubação equivalente a 100% da recomendação de potássio é excessiva para o cultivo do maracujazeiro-amarelo 'BRS GA1' no semiárido tropical, sob condições de estresse salino.

Palavras-chave: *Passiflora edulis* Sims, estresse salino, adubação potássica, semiárido.

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1. Introduction

Yellow passion fruit (*Passiflora edulis* Sims) is a fruit crop widely cultivated and consumed in Brazil (Monzani et al., 2018). Passion fruit has vitamin A, C, and B complex, minerals such as potassium, iron, and calcium. Passion fruit peel is also rich in soluble fiber, mainly pectin and niacin (vitamin B3), iron, calcium, and phosphorus (Zeraik et al., 2010).

In the semiarid region of Northeast Brazil, most groundwater sources contain high levels of salts which cause damage to agricultural production (Lima et al., 2018a; Lima et al., 2018b). Salt stress provokes deleterious effects on plants due to osmotic and ionic effects, limiting physiological and metabolic processes (Dias et al., 2019; Silva et al., 2022a). However, the damage to crop yield can be reduced by employing management strategies (Silva et al., 2021) adopted to decrease the harmful effect of salts (Medeiros et al., 2017), thereby avoiding soil degradation due to salinization.

The application of brackish water only in the determined growth stage(s) with greater salt tolerance is a promising alternative for cultivation in semiarid regions. For example, evaluating the potential of the use of brackish water in colored cotton genotypes, Soares et al. (2020) concluded that stress during the flowering and yield formation phases increases fiber weight and fiber quality, while Silva et al. (2022b) in the case of mini watermelon Sugar Baby observed that the use of high salinity water in the flowering and fruit maturation phases does not compromise its production.

Another alternative for attenuating the effects of salts on plants is mineral fertilization. In this context, potassium is a nutrient responsible for protein synthesis, enzymatic activation, and carbohydrate metabolism, besides assisting in the process of osmoregulation, movement of water in the cell, and energy transfer (Wang et al., 2013). In addition, this nutrient can promote the accumulation of osmolytes and increase antioxidant components in plants exposed to salt stress (Ahanger et al., 2017).

Although several studies address the effects of salt stress on passion fruit (Lima et al., 2021; Sá et al., 2021; Silva et al., 2021), the tolerance of this crop to salinity varies according to crop development stage (Soares et al., 2021). In this context, the objective of this study was to determine the quantum yield, chlorophyll levels, and cell damage in yellow passion fruit cultivated under different irrigation strategies with brackish water and potassium fertilization in the second year of its cultivation.

2. Material and Methods

The experiment was carried out from August 2019 to October 2020 under field conditions at the 'Rolando Enrique Rivas Castellón Experimental Farm (06º48'50" S; 37º56'31" W, 190 m), Pombal, PB, Brazil. Data of temperature (maximum and minimum), relative humidity of the air, and precipitation during the experimental period are shown in Figure 1. Precipitation began 138 days after transplanting (DAT), with a total accumulated volume of 1145 mm.

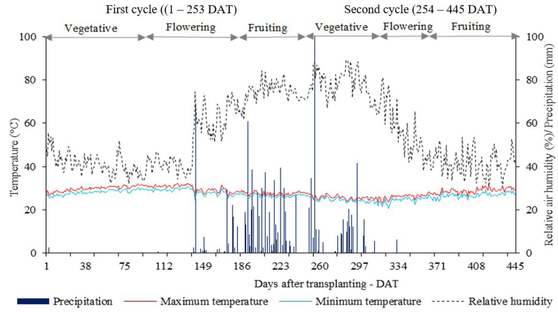

Figure 1. Data of precipitation, maximum and minimum air temperatures, and relative humidity of air observed during the experimental period.

The treatments were distributed in randomized blocks in a 6×2 factorial scheme with four replications, each plot consisting of 3 plants. Six strategies of brackish water use in irrigation: 1. WS - irrigation with low-salinity water (1.3 dS m^{-1}) throughout the crop cycle - control (254- 445 days after transplanting - DAT); 2. irrigation with high salinity water (4.0 dS m^{-1}) in the VE - vegetative stage (254 - 340 DAT); 3. FL - flowering stage (341-360 DAT); 4. FR - fruiting stage (361 - 445 DAT); 5. VE and FL stages (254-360 DAT); 6. VE and FR stages (254-340 and 361-445 DAT). The second factor was composed of two potassium doses (60 and 100% of the potassium recommendation of Costa et al., 2008) for the crop. The dose of 100% potassium corresponded to application of 345 g of K_2O per plant per year (Costa et al., 2008).

Seeds of 'BRS GA1' yellow passion fruit were used. For seedling formation, seeds were sown in plastic bags with dimensions of 15×20 cm, filled with substrate consisting of 84% of autoclaved soil, 15% of autoclaved sand (aiming to avoid possible problems with fusariosis during the seedling formation stage), and 1% decomposed bovine manure (v/v basis).

The soil of the experimental area was classified as Entisol of a sandy loam texture. The tillage practices consisted of plowing followed by harrowing to break up soil clods and leveling the area. Before transplanting the seedlings to the field, soil samples were collected in the 0-0.40 m depth at 5 points in the experimental area and then mixed to form a composite sample. The chemical and physical characteristics of the soil were determined (Table 1) according to the methodologies described by (Teixeira et al., 2017).

The dimensions of the planting pit holes were 0.40×0.40×0.40 m. After opening the pits, fertilization with 20 L of bovine manure and 50 g of single superphosphate (17% P_2O_5) was carried out as recommended by Costa et al. (2008). Nitrogen and potassium were applied monthly, using urea (45% N) and potassium chloride (60% K_2O). Nitrogen was applied at 65 g per plant in the crop formation (vegetative stage) and 160 g in the flowering and fruiting stages in each cycle. Plots under the dose of 100% potassium received 65 g of K_2O per plant in the crop formation stage and 280 g in the flowering and fruiting stages, while the other plots received 60% of this dose.

Micronutrient application was performed fortnightly using Dripsol micro® (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% with 70% EDTA chelating agent) at concentration of 1 g L^{-1}, via foliar spraying on the abaxial and adaxial sides of the leaves.

The spacing between rows and plants was 3 m. Nylon string was used to guide the plants to the trellis system at 1.80 m height. When the plants reached 10 cm above the trellis, the apical bud was pruned to induce the growth of two secondary branches, one on each side up to 1.5 m. After the secondary branches reached this length, a new pruning of the apical buds was performed to induce the growth of tertiary branches, which were allowed to grow downwards up to 0.30 m from the ground. Throughout the experiment, tendrils and unwanted branches were eliminated to favor the development of the crop.

The irrigation water of the low electrical conductivity (1.3 dS m^{-1}) was obtained from an artesian well located in the experimental area, the results of analysis are presented in Table 2. While the water with ECw of 4.0 dS m^{-1} was prepared by dissolving NaCl in well water, considering the relationship between ECw and salt concentration (Richards, 1954), according to Equation 1. After preparation, the electrical conductivity of water was verified and adjusted to the desired level.

$$C \approx 640 \times \left(4 - ECw\right) \quad (1)$$

where: C = salt concentration (mg L^{-1}); ECw = electrical conductivity of well water used (dS m^{-1})

At 61 days after sowing (DAS), the seedlings were transplanted to the field. The irrigation with brackish water started at 50 DAT. Irrigation was applied through a localized drip system, using 32-mm-diameter PVC pipes in the mainline and 16-mm-diameter low-density polyethylene pipes in the lateral lines with drippers (10 L h^{-1}). Two pressure-compensating drippers (GA 10 Grapa model) were installed for each plant, each 15 cm away from the stem. Plants were irrigated daily at 7:00 a.m., with respective water according to the adopted strategy, and the irrigation depth applied was based on crop evapotranspiration and considering the precipitation events according to Bernardo et al. (2013) obtained by Equation 2:

$$ETc = ETo \times Kc \quad (2)$$

where: ETc - crop evapotranspiration, mm day^{-1}; ETo - Penman-Monteith reference evapotranspiration, mm day^{-1}; and Kc - crop coefficient, dimensionless.

Reference evapotranspiration (ETo) was determined daily according to FAO 56 (Allen et al., 1998) from climatic data collected at the São Gonçalo Meteorological Station, located in the municipality of Sousa – PB, about 54 km from the experimental area. The crop coefficients (Kc) used were: 0.4 for the vegetative stage, 0.8 for the flowering, and 1.2 for the fruiting period, according to the recommendation of Nunes et al. (2017).

The second cycle began after the corrective pruning of the crown carried out at the end of the harvest of the first cycle (254 DAT) to promote aeration and entry of sunlight into the plants, in addition to the renewal of productive branches eliminating dead, old and/or unproductive branches. After pruning tertiary and quaternary branches, about 0.40 m from the wire, the plants were irrigated for 10 days with water of low electrical conductivity.

Table 1. Chemical and physical characteristics of the soil (0-0.40 m depth) of the experimental area.

Chemical characteristics								
pH H_2O)	**OM**	**P**	**K^+**	**Na^+**	**Ca^{2+}**	**Mg^{2+}**	**Al^{3+}**	**H^+**
(1:2.5)	**dag kg^{-1}**	**(mg kg^{-1})**	**..........cmol$_c$ kg^{-1}..........**					
7.82	0.81	10.60	0.30	0.81	2.44	1.81	0	0
..........Chemical characteristics............				**..........................Physical characteristics...........................**				
EC_{se}	**CEC**	**SAR_{se}**	**ESP**	**Particle-size fraction (g kg^{-1})**			**Soil moisture (g g^{-1})**	
(dS m^{-1})	**cmol$_c$ kg^{-1}**	**(mmol L^{-1})$^{0.5}$**	**%**	**Sand**	**Silt**	**Clay**	**33.42 kPa[1]**	**1519.5 kPa[2]**
1.52	5.36	6.67	15.11	820.90	170.10	9.00	0.1287	0.0529

pH – Hydrogen potential, OM – Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 M KCl at pH 7.0; Na^+ and K^+ extracted with 1 M NH_4OAc at pH 7.0; Al^{3+} + H^+ extracted with 0.5 M CaOAc at pH 7.0; EC_{se} - Electrical conductivity of saturation extract; CEC - Cation exchange capacity; SAR_{se} - Sodium adsorption ratio of saturation extract; ESP - Exchangeable sodium percentage; [1,2] refer to field capacity and permanent wilting point, respectively.

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

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

EC - electrical conductivity. SAR - sodium adsorption ratio.

During the experiment, cultural practices and phytosanitary treatments recommended for the crop were carried out, with weed control every 30 days, monitoring the attacks of pests and diseases, and adopting control measures whenever necessary. The fungicide Ridomil gold MZ® (250 g $100L^{-1}$) and the acaricide/fungicide Dithane® (350 g $100L^{-1}$) were applied to prevent fungi, while Decis 25 EC® (30 mL $100L^{-1}$) and Lannate® (100 mL $100L^{-1}$) were applied to control pests.

At 340, 360, and 445 DAT, chlorophyll *a* fluorescence was evaluated through initial fluorescence (F_0), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm), using Opti Science OS5p pulse-modulated fluorometer. The leaves were pre-adapted to the dark for 30 minutes using leaf clips to ensure that all the first acceptors were oxidized, i.e., the reaction centers were open (Kitajima & Butler, 1975). The measurements were performed between 7:00 and 10:00 a.m. on the median leaf of the intermediate productive branch.

At the same evaluation times, photosynthetic pigments (chlorophyll *a*, chlorophyll *b*, chlorophyll *total*, and carotenoids) were quantified according to Arnon (1949). For determination of intercellular electrolyte leakage, eight leaf discs (113 mm^2) per sample were rinsed with distilled water and stored in a covered becker with 50 mL of deionized water for 90 minutes. After that, the measurement of initial electrical conductivity (Xi) was performed. Then, the beakers were subjected to a temperature of 80 °C in an oven with forced-air ventilation for 90 min, and after cooling the contents, the final electrical conductivity (Xf) was measured. Intercellular electrolyte leakage in the leaf blade was quantified according to Scotti-Campos et al. (2013), as shown in Equation 3:

$$\%\ \text{IEL} = \frac{\text{Xi}}{\text{Xf}} \times 100 \tag{3}$$

where:

% IEL = Intercellular electrolyte leakage (%); Xi = initial electrical conductivity (dS m^{-1}); and Xf = final electrical conductivity (dS m^{-1});

The relative water content (RWC) was determined using three fully formed leaves of each plant, which were detached and immediately weighed on a scale with a resolution of 0.001 g; to determine the mass of turgid leaves (TM), the collected leaves were immersed in distilled water for 12 hours, dried in a paper towel and weighed, and the dry mass was obtained by drying these leaves in an oven at 65 °C until constant weight. RWC was obtained with Equation 4, according to Lima et al. (2015):

$$\text{RWC} = \frac{(\text{FM - DM})}{(\text{TM - DM})} \times 100 \tag{4}$$

where: RWC = relative water content (%); FM = leaf fresh mass (g); TM = leaf turgid mass (g); DM = leaf dry mass (g).

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

3. Results and Discussion

There were significant effects of brackish water irrigation strategies (BWIS) on F_0, at 360 and 445 DAT, on Fm, at 340, 360, and 445 DAT, and on Fv/Fm, at 340 and 360 DAT; potassium doses (KD) did not significantly affect any fluorescence variables, and the interaction between factors (BWIS × KD) caused a significant effect only on Fv at 360 DAT (Table 3).

At 360 DAT, plants under the VE strategy reached higher values of F_0 compared to those under the other strategies, whereas at 445 DAT, plants irrigated with brackish water in the VE, FL, and FR stages stood out with F_0 differing from the values found under other irrigation strategies (Table 4). An increase in the value of F_0 is indicative of damage to the photosynthetic apparatus because it is a sign of loss of light energy, which can also affect the energy transfer of photosystem II (PSII) (Silva et al., 2014) and may be due to oxidative damage to the light-harvesting complex and PSII reaction center, as well as to the size of the collecting antenna (Horton, 2012).

The F_0 of yellow passion fruit plants increased with the salt stress imposed in the VE, FL, and FR stages (Table 4), causing damage to the photosynthetic apparatus. In general, most crops are more sensitive to salt stress in the initial stages (Araújo et al., 2016) which justifies the increase in the F_0 of yellow passion fruit plants irrigated with high salinity water in the vegetative stage. The increase in the F_0 of passion fruit plants cultivated with high-salinity water in the FL and FR stages may be due to the absence of precipitation in this growing period (Figure 1), so there was no mitigating effect of rains on plants in these phenological stages.

At 360 DAT (Table 5), plants under the WS strategy obtained the smallest values of Fm lower than the value found under the other strategies. At 445 DAT plants subjected to the WS and VE/FL strategies also stood out with the lowest Fm values, differing statistically from those under the other irrigation strategies. Fm is related to the maximum intensity of the fluorescence emitted when almost all quinone is reduced and the reaction centers reach their highest capacity for photochemical reactions, a process that requires electrons from water (Silva et al., 2015); therefore, the decrease observed in plants under the VE/FL strategy indicates a slowdown in photosynthetic activity which aims to reduce the harmful effects of salt stress.

At 340 DAT, the lowest values of Fv/Fm were observed in plants under VE and VE/FL strategies, differing from other treatments; at 360 DAT, the plants under WS, VE, and FR strategies reached lower values of Fv/Fm (Table 5). Mean Fv/Fm values ranging from 0.75 to 0.85 indicate that the photosynthetic apparatus is intact. Although there were significant differences among the BWIS, the values obtained are within the Fv/Fm range recommended by Bolhàr-Nordenkampf et al. (1989).

Table 3. Summary of the analysis of variance for initial fluorescence (F_0), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm) of 'BRS GA1' yellow passion fruit cultivated under brackish water irrigation strategies (BWIS) and potassium doses (KD), 340, 360, and 445 days after transplanting.

SV/DF	DAT	BWIS	KD	Interaction (BWIS ×KD)	Blocks	Residue	CV%
		5	1	5	3	33	
		Mean squares					
F_0		9111.8^{ns}	22446.7^{ns}	2170,1^{ns}	12400,6^{ns}	4279.2	10.24
Fv		64291.5^{ns}	90046.6^{ns}	50137,4^{ns}	170776,6^{ns}	63572.3	12.37
Fm	340	362151.8**	216008.3^{ns}	51,921,8^{ns}	109724,3^{ns}	97624.9	12.03
Fv/Fm		0,00099*	0.000052^{ns}	0,00056^{ns}	0,00074^{ns}	0.00031	2.33
F_0		25443.4*	11563.0^{ns}	5989,4^{ns}	2676,6^{ns}	4264.4	11.91
Fv		81555.6^{ns}	12675.0^{ns}	120479,6*	21084,2^{ns}	35309.3	10.14
Fm	360	244611.8*	760.0^{ns}	53562,1^{ns}	4977,0^{ns}	46979.1	9.38
Fv/Fm		0.0004**	0.0002^{ns}	0,0001^{ns}	0,0002^{ns}	0.0001	1.54
F_0		40030.10**	49152.00^{ns}	3842,30^{ns}	875,16^{ns}	4960.10	11.25
Fv	445	41669.4^{ns}	53600.3^{ns}	13196,5^{ns}	116310,9^{ns}	21528.9	8.81
Fm		219755.8*	22533.3^{ns}	97131,5^{ns}	281737,1^{ns}	62593.8	11.17
Fv/Fm		0.0006^{ns}	0.001^{ns}	0.0008^{ns}	0.0004^{ns}	0.0006	3.55

DAT- Days after transplanting, SV - Source of variation; DF – Degrees of freedom; CV (%) – Coefficient of variation; *significant at 0.05 probability level; **significant at 0.01 probability level; ^{ns}not significant.

Table 4. Initial fluorescence (F_0) of 'BRS GA1' yellow passion fruit as a function of the use of brackish water irrigation strategies (BWIS), 360 and 445 days after transplanting.

BWIS	F_0	
	Days after transplanting - DAT	
	360	445
WS	506.25±21.18 b	542.37±46.11 b
VE	658.37±20.88 a	680.87±33.09 a
FL	556.00±20.45 b	659.25±36.01 a
FR	528.12±22.40 b	720.87±56.01 a
VE/FL	526.87±19.97 b	584.75±34.15 b
VE/FR	515.25±17.77 b	569.37±18.01 b

Means followed by the same letters indicate no significant difference between brackish water irrigation strategies by the Scott-Knott test (p≤0.05). Mean ± standard error (n = 4); WS - irrigation with low-salinity water throughout the crop cycle; salt stress in the VE - vegetative stage, FL - flowering stage, FR - fruiting stage, VE/FL - vegetative and flowering stages, and VE/FR - vegetative and fruiting stages.

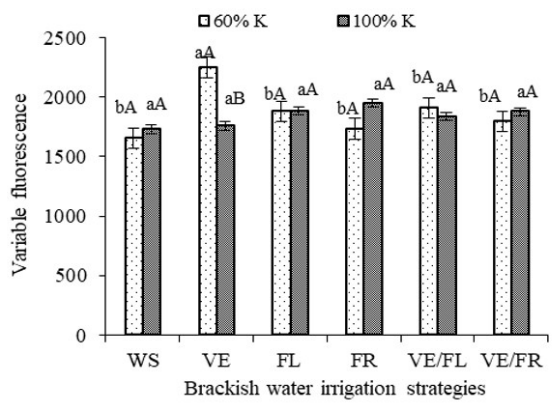

Figure 2. Variable fluorescence – Fv of 'BRS GA1' yellow passion fruit plants as a function of the interaction between brackish water irrigation strategies and potassium doses at 360 days after transplanting. Vertical bars represent the standard error of the mean (n = 4). Means followed by the same lowercase letters indicate no significant difference between brackish water irrigation strategies by the Scott-Knott test (p≤0.05) for the same potassium dose; the same uppercase letter indicates no significant difference between potassium doses by the F test (p ≤0.05) for the same strategy. For details of BWIS see Table 4.

It is important to highlight that the Fv/Fm values are within the range considered without indicative of a harmful effect on the photosynthetic apparatus (Fv/Fm > 0.75) of the passion fruit plants. Normally, plants grown under stress conditions, especially saline, undergo changes in water status, and the optical properties of leaves can change markedly and cause changes in the PSII fraction and the structure of the thylakoid membrane (Baker, 2008).

Analysis of the interaction of BWIS at each K dose for Fv (Figure 2) at 360 DAT showed significant differences in plants fertilized with 60% of the potassium recommendation resulting in higher variable fluorescence in plants submitted to irrigation with high salinity water at the VE stage, while under the K dose of 100% recommendation, there were no differences among the BWIS. When comparing the doses of 60 and 100% of the K recommendation, a significant difference was observed only in plants subjected to salt stress in the VE stage. In the initial phase of development, plants are usually more sensitive to the stress condition due to the smaller amount of vacuoles to store toxic ions that disturb aerobic metabolism and induce the accumulation of reactive oxygen species, in addition to affecting the plant's ability to detoxify cellular oxidants, which in turn negatively affect cellular structures and metabolism (Almeida et al., 2017).

Fertilization with a higher dose of KCl due to its high salt index may have intensified the osmotic effect (Dias et al., 2019), hindering the absorption of water and nutrients, and affecting plant growth and physiological processes. In addition, according to Hubbart et al. (2018), the reduction in Fv at 360 DAT can be either due to an increase in F_0 (possible indication of damage to the PSII) or a decrease in Fm (activation of photoprotection mechanisms).

There were significant effects of BWIS on chlorophyll *a* (360 and 445 DAT), chlorophyll *b* (340 and 445 DAT), carotenoids (340 and 360 DAT), intercellular electrolyte leakage - % IEL (340, 360, and 445 DAT), relative water content - RWC (340, 360, and 445 DAT) (Table 6). But potassium doses (KD) did not significantly influence pigments, % IEL, and RWC. The interaction between factors

Table 5. Maximum fluorescence (Fm) and maximum quantum efficiency of photosystem II – (Fv/Fm) of 'BRS GA1' yellow passion fruit as a function of the use of brackish water irrigation strategies (BWIS), 340, 360, and 445 days after transplanting.

BWIS	Fm		Fv/Fm	
	Days after transplanting - DAT			
	360	445	340	360
WS	1983.0±83.8 b	1972.6±86.9 b	0.774±0.006 a	0.768±0.006 b
VE	2274.2±30.8 a	2372.6±96.0 a	0.750±0.010 b	0.771±0.009 b
FL	2486.5±81.1 a	2346.0±73.2 a	0.766±0.006 a	0.789±0.004 a
FR	2367.8±105.3 a	2375.2±93.0 a	0.771±0.005 a	0.776±0.004 b
VE/FL	2399.6±87.2 a	2125.5±169.4 b	0.748±0.016 b	0.779±0.004 a
VE/FR	2356.3±66.3 a	2243.0±120.4 a	0.768±0.010 a	0.781±0.006 a

Means followed by the same letters indicate no significant difference between brackish water irrigation strategies by the Scott-Knott test (p≤0.05). Mean ± standard error of mean (n = 4); For details of BWIS see Table 4.

Table 6. Summary of the analysis of variance for chlorophyll *a* (*Chl a*), chlorophyll *b* (*Chl b*), carotenoids (*Car*), intercellular electrolyte leakage (% IEL), and relative water content (RWC) of 'BRS GA1' yellow passion fruit cultivated under brackish water irrigation strategies (BWIS) and potassium doses (KD) at 340, 360 e 445 days after transplanting (DAT).

SV/DF	DAT	BWIS	KD	Interaction (BWIS ×KD)	Blocks	Residue	CV%
		5	1	5	3	33	
Mean squares							
Chl a	340	1.09^{ns}	0.36^{ns}	7.19^{ns}	4.22^{ns}	3.89	64.22
Chl b		1.10^{**}	0.13^{ns}	0.34^{ns}	0.16^{ns}	0.22	54.54
Car		2.14^{**}	0.85^{ns}	0.71^{ns}	0.40^{ns}	0.36	48.38
% IEL		46.7^{**}	4.05^{ns}	4.4^{ns}	2.6^{ns}	4.80	16.00
RWC		801.95^{**}	17.01^{ns}	23.73^{ns}	11.99^{ns}	28.82	9.63
Chl a	360	23.85^{*}	1.10^{ns}	9.84^{ns}	23.97^{ns}	5.30	33.88
Chl b		1.97^{ns}	7.10^{ns}	3.85^{ns}	0.99^{ns}	3.90	87.39
Car		3.97^{**}	2.54^{ns}	0.51^{ns}	3.41^{ns}	1.10	48.02
% IEL		117.58^{**}	2.77^{ns}	1.70^{ns}	4.25^{ns}	2.51	9.28
RWC		476.9^{**}	8.8^{ns}	103.2^{**}	14.70^{ns}	31.70	7.62
Chl a	445	0.72^{**}	0.15^{ns}	0.02^{ns}	0.0063^{ns}	0.053	29.32
Chl b		0.64^{**}	0.01^{ns}	0.27^{ns}	0.04^{ns}	0.16	40.61
Car		0.55^{ns}	0.41^{ns}	0.65^{ns}	0.16^{ns}	0.28	33.55
% IEL		73.74^{*}	0.59^{ns}	31.65^{*}	2.36^{ns}	11.76	24.16
RWC		306.31^{**}	0.77^{ns}	30.11^{ns}	21.81^{ns}	54.11	10.59

SV – Source of variation; DF – Degrees of freedom; CV (%) – Coefficient of variation; *significant at 0.05 probability level; **significant at 0.01 probability level; ^{ns}not significant.

(BWIS × KD) had significant effects on % IEL (445 DAT) and RWC (360 DAT) (Table 6).

At 360 DAT, plants under the VE/FL strategy showed lower mean values of *Chl a*, while at 445 DAT, plants under the WS strategy were superior to the all other treatments (Table 7). At 340 DAT, plants under the WS strategy had higher values of Chl *b*; however, at 445 DAT, plants under the VE strategy showed the highest values of Chl *b*.

In general, the salt stress applied to passion fruit plants under different irrigation strategies reduced *Chl a* and *Chl b* contents, except for plants at 445 DAT (Table 7). Such a reduction in contents of chlorophyll *a* and chlorophyll *b* may be a result of both the degradation of pigment molecules by the action of the chlorophyllase enzyme and decrease in the chlorophyll synthesis induced by high salinity (Nunkaew et al., 2014). Salt stress inhibits the synthesis of 5-aminolevulinic acid, a precursor of the chlorophyll molecule, that induces the activity of chlorophyllase (Taiz et al., 2017) an enzyme that acts on the degradation of photosynthetic pigment molecules. Chlorophyll degradation can also be related to photooxidation caused by secondary oxidative stress (Freire et al., 2013).

At 340 DAT, plants cultivated under salt stress in the VE, FL, FR, VE/FL, and VE/FR stages reached lower *Car* values, which also occurred at 360 DAT except for plants under the VE/FR strategy (Table 7). The reduction in carotenoid content occurs due to the degradation of β-carotene; as a result, it can cause decreases in carotenoid content, which are integrated components of thylakoids, acting in the absorption and transfer of light to chlorophyll (Silva et al., 2016).

Plants under the strategies VE, FL, VE/FL, and VE/FR had higher values of % IEL (Table 8). Plants under salt stress, irrespective of the phenological stage, had lower RWC values, the most affected being at stages of VE and VE/FL at 340 DAT. In general, salt stress applied in the different phenological stages of the yellow passion fruit plants compromised their % IEL and RWC (Table 8). These responses can result in membrane destabilization and cell turgor loss, impacting growth and photosynthetic processes. Intercellular electrolyte leakage can be related to the increase of reactive oxygen species (ROS) under salt stress, as by-products that impair cellular components, degrade photosynthetic pigments, and cause lipid peroxidation, reducing membrane fluidity and selectivity (Taibi et al., 2016).

For % IEL at 445 DAT (Figure 3A), a significant effect is observed for the interaction between the studied factors. When analyzing the BWIS at each potassium dose, it is observed that plants fertilized with 60% of the potassium recommendation and irrigated with brackish water in the VE, FR, VE/FL, and VE/FR stages showed significantly higher % IEL. Similar results were observed for plants fertilized with 100% potassium recommendation, where the VE, FL, VE/FL, and VE/FR strategies led to higher mean values compared to the others. In general, the interaction between irrigation water salinity (4.0 dS m^{-1}) and potassium fertilization interfered in the water relations of yellow passion fruit plants, causing an increase in % IEL (Figure 3A), which demonstrates that salt stress caused by irrigation water salinity can be intensified with the dose of potassium fertilization.

For RWC at 360 DAT (Figure 3B), the analysis of BWIS within the K dose of 60% showed that plants under the strategies VE/FL and VE/FR were inferior to those under the other strategies. A similar result was observed for plants fertilized with 100% potassium dose, but those under the VE strategy also attained lower RWC values. Regarding the analysis of potassium doses within BWIS, there was a significant difference for plants grown under salt stress in the VE stage, where the dose of 100% potassium led to lower RWC values.

High-salinity water caused a reduction in the RWC of yellow passion fruit plants, especially when applied in the VE, FL, VE/FL, and VE/FR stages. The reduction observed with the VE and FL strategies reflects the sensitivity of the crop to salt stress. On the other hand, the reduction observed with the VE/FL and VE/FR strategies can be justified by the previous findings of Sousa et al. (2011), who reported that a longer duration of salt stress can cause more damage to plants. Furthermore, the decrease in the relative water content of the leaves initially induces stomatal closure, causing a decline in the CO_2 concentration in the mesophyll cells and, consequently, resulting in a reduction of net photosynthesis rate (Baker & Rosenqvist, 2004).

Table 7. Chlorophyll *a* - *Chl a* (mg g^{-1} FM), chlorophyll *b* - *Chl b* (mg g^{-1} FM), and carotenoids – *Car* (mg g^{-1} FM) of 'BRS GA1' yellow passion fruit as a function of the use of brackish water irrigation strategies (BWIS), at 340, 360 and 445 days after transplanting.

BWIS	***Chl a***		***Chl b***		***Car***	
	Days after transplanting - DAT					
	360	**445**	**340**	**445**	**340**	**360**
WS	8.58±2.13 a	1.39±0.14 a	1.60±0.56 a	0.76±0.21 b	2.24±0.43 a	2.75±0.60 a
VE	7.32±1.92 a	0.62±0.41 b	0.62±0.52 b	1.53±0.68 a	0.77±0.43 b	2.02±0.45 b
FL	6.84±1.67 a	0.73±0.18 b	0.69±0.43 b	0.88±0.17 b	1.06±0.25 b	1.90±0.45 b
FR	7.55±1.65 a	0.62±0.12 b	0.65±0.42 b	0.91±0.17 b	0.95±0.36 b	2.22±0.56 b
VE/FL	3.50±1.21 b	0.62±0.17 b	0.78±2.05 b	0.81±0.22 b	1.30±0.38 b	1.09±0.33 b
VE/FR	6.97±2.33 a	0.74±0.10 b	0.84±0.81 b	1.07±0.14 b	1.18±0.45 b	3.11±0.90 a

Means followed by the same letters indicate no significant difference between brackish water irrigation strategies by the Scott-Knott test (p≤0.05). Mean ± standard error (n = 4); For details of BWIS see Table 4.

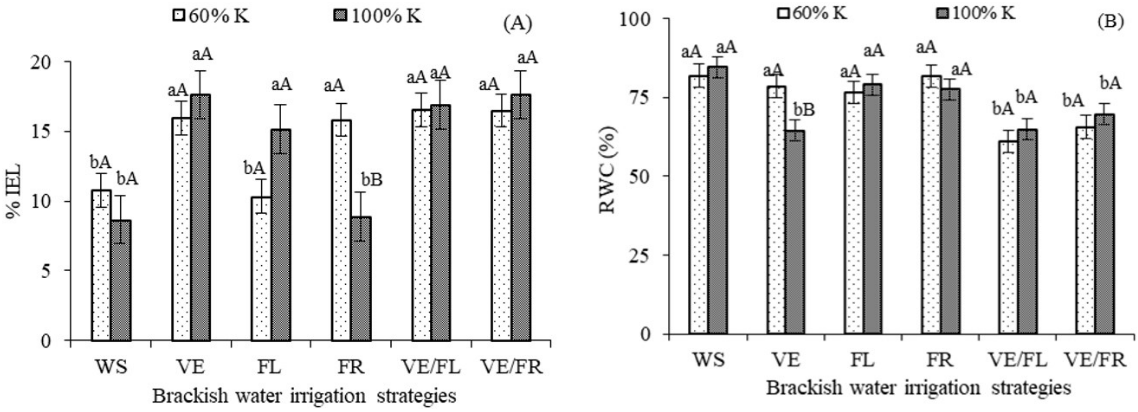

Figure 3. Electrolyte leakage - % IEL (A) and relative water content - RWC (B) of yellow passion fruit plants 'BRS GA1' as a function of the interaction between the use of brackish water irrigation strategies and potassium doses at 445 and 360 days after transplanting, respectively. Vertical bars represent the standard error of mean (n = 4). Means followed by the same lowercase letters indicate no significant difference between management strategies by the Scott-Knott test (p≤0.05) for the same potassium dose, and the same uppercase letters indicate no significant difference between potassium doses by the Tukey test (p ≤ 0.05) for the same strategy. For details of BWIS see Table 4.

Table 8. Electrolyte leakage - % IEL and relative water content – RWC (%) of 'BRS GA1' yellow passion fruit as a function of the use of brackish water irrigation strategies (BWIS), 340 days after transplanting.

BWIS	% IEL	RWC
WS	10.96±1.01 b	74.74±2.65 a
VE	15.06±0.69 a	46.66±3.13 c
FL	13.56±0.80 a	56.69±2.52 b
FR	10.86±0.94 b	59.94±2.94 b
VE/FL	15.11±0.44 a	49.21±4.39 c
VE/FR	16.53±1.43 a	52.20±4.80 b

Means followed by the same letters indicate no significant difference between brackish water irrigation strategies by the Scott-Knott test (p≤.05). Mean ± Standard error (n = 4); For details of BWIS see Table 4.

It is worth pointing out that, for RWC, in the interaction between the studied factors (BWIS × KD), the application of irrigation with water of 4.0 dS m^{-1} in the fruiting stage (FR), regardless of the dose of potassium fertilization may be an alternative for the utilization of water of higher electrical conductivity by farmers, especially in semiarid regions. Usually, when plants are in the fruiting (FR) stage, they commonly have higher energy expenditure due to fruit filling, so the maintenance of water status is desirable to perform their metabolic activities.

4. Conclusions

The use of brackish water (4.0 dS m^{-1}) increases chlorophyll fluorescence and negatively affected the photosynthetic pigments of yellow passion fruit, regardless of the phenological stage.

Salt stress intensifies intercellular electrolyte leakage in the leaf, especially in plants fertilized with 100% potassium recommendation (345g per plant per year).

Fertilization with 60% potassium recommendation increases the relative water content of yellow passion fruit plants subjected to salt stress in the vegetative phase, at 360 and 445 days after transplanting.

Fertilization with 100% of the potassium recommendation is excessive for yellow passion fruit 'BRS GA1' in the tropical semiarid region under conditions of salt stress. In general, yellow passion fruit is sensitive to saline stress in the vegetative phase and tolerant in the fruiting phase.

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