

# SALT STRESS ON PHYSIOLOGY, BIOMETRY AND FRUIT QUALITY OF GRAFTED *Passiflora edulis*

## ESTRESSE SALINO NA FISILOGIA, BIOMETRIA E QUALIDADE DE FRUTOS DE *Passiflora edulis* ENXERTADO

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**ABSTRACT:** The production of grafted passion fruit is an alternative for plant adaptation to saline environments. The objective of this study was to evaluate the effect of salt stress on physiology, biometry and fruit quality of *P. edulis* grafted on *Passiflora* spp. The experiment was conducted in completely randomized design, in a 3 x 2 factorial scheme, corresponding to three species of *Passiflora* (*P. edulis*, *P. gibertii* and *P. cincinnata*) with *P. edulis* scion and two levels of irrigation water salinity (0.5 - control and 4.5 dS m<sup>-1</sup>), with four repetitions. Water salinity compromises gas exchanges (CO<sub>2</sub> assimilation rate and transpiration) and physiological variables (total chlorophyll and total water consumption) in grafted *P. edulis*. The interaction between the factors (water salinity x species) compromised only the growth in plant height and number of leaves. In relation to the species, auto-grafted *P. edulis* stood out from the other species, with higher internal CO<sub>2</sub> concentration, number of leaves, stem dry mass, peel thickness, total soluble solids (TSS) of the pulp and TSS/TA ratio (titratable acidity). Auto-grafted *P. edulis* under saline conditions develops vital mechanisms (TSS and TSS/TA), which attenuates the effects of salt stress on the physico-chemical quality of the fruits.

**KEYWORDS:** Grafting. *Passiflora cincinnata*. *Passiflora gibertii*. Salinity. Gas exchanges.

### INTRODUCTION

Brazil is the main producer of yellow passion fruit (*Passiflora edulis* Sims), with the Northeastern region and the state of Bahia producing 70% and 48.73%, respectively, of the national production of 704 thousand tons (IBGE, 2018). Such production is attributed to its favorable edaphoclimatic conditions for the exploitation of the crop, with the exception of rainfall. Despite the significant production of yellow passion fruit, the Northeast region faces problems of soil salinization, especially under irrigated conditions, thus compromising the establishment of orchards. This is more evident in irrigated perimeters, due to inadequate irrigation management, associated with soil drainage problems and high evapotranspiration (BRITO et al., 2014; LEITE; GOMES; SANTOS, 2015; GADELHA et al., 2017).

Excess salts in water and/or in soil adversely affect the gas exchange, growth, yield and fruit quality, as they result in alteration in the physiological and biochemical functions of the plants, resulting in disturbances in water relations, changes in the absorption and use of essential nutrients, in addition to the accumulation of potentially toxic ions, especially Na<sup>+</sup> and Cl<sup>-</sup>

(NEVES et al., 2009; RIBEIRO et al., 2009; AMORIM et al., 2010). Regarding the water relations and gas exchange in plants under salt stress, there is a restriction in the availability of water due to the osmotic effect; consequently, stomatal closure limits stomatal conductance and transpiration, which reduces the rate of photosynthesis. It is known that the influx of CO<sub>2</sub> is necessary through the stomata in the photosynthetic process, and water efflux also occurs through transpiration. Stomatal movement is the main mechanism of control of gas exchange in higher plants (SILVA et al., 2010).

In recent years, several studies have been carried out to evaluate the deleterious effects of salt stress on the yellow passion fruit crop (MONTAÑA, et al., 2014, FREIRE et al., 2014; MOURA et al., 2016a; SOUZA et al., 2016; MOURA et al., 2017), but these studies are limited to analyzing only the effect of irrigation with waters of different levels of salinity on plants produced by seeds in the phase of seedling formation. To date, there is no information in the literature on the behavior of auto- and interspecific-grafted passion fruit plants under salt stress conditions in the fruiting stage on fruit quality.

Yellow passion fruit is traditionally grown through seeds; however, in order to minimize phytosanitary problems caused by soil pathogens, many researchers have studied the grafting of commercial species using rootstocks of wild species resistant to soil pathogens, mainly of the genus *Fusarium* (SANTOS et al., 2016; SCHMILDT et al., 2018), *P. edulis*/*P. gibertii* (CAVICHIOLOI et al., 2011); *P. edulis* / *P. mucronate* (ALEXANDRE et al., 2013); *P. edulis*/*P. mucronate* (OLIARI et al., 2016); *P. nitida*/*P. edulis*, *P. gibertii*/*P. edulis*, *P. alata* - *P. edulis* (LIMA et al., 2017b).

However, most of these wild species have mechanisms of tolerance to water and salt stress because they are native to semi-arid regions. Thus, it is very opportune to study these species as rootstocks under conditions of salt stress for use in the agricultural sector. It is important to emphasize the desirable aspects in these plants after grafting, as these develop mechanisms to attenuate the effects of salt stress, such as stomatal regulation and compartmentalization of ions ( $\text{Na}^+$  and  $\text{Cl}^-$ ) in the vacuoles, maintaining a favorable  $\text{K}^+/\text{Na}^+$  balance in the cytosol, allowing the development and production of the crop (SILVEIRA et al., 2016).

In this context, there is a need to adopt cultivation technologies that attenuate the deleterious effects of excess salts in irrigation water during the entire growth and production phase of the crop, especially with techniques that allow satisfactory agricultural production. The objective of this study was to evaluate the effect of salt stress on the physiology, biometry and fruit quality of *P. edulis* grafted on *Passiflora* spp.

## MATERIAL AND METHODS

### Location of experiment

The experiment was conducted in the experimental area of Embrapa Cassava and fruits, in Cruz das Almas, BA (Latitude of 12°48'19" S, Longitude of 39°06'23" W and altitude of 225 m), from March 2016 to August 2017, with mean annual rainfall, temperature and relative humidity of 1,224 mm, 24.5 °C and 80%, respectively (EMBRAPA, 2016).

### Experimental design and vegetative material

The experiment was conducted in a completely randomized design, in a 3 x 2 factorial scheme, with three species of *Passiflora* (*P. edulis*, *P. gibertii* and *P. cincinnata*) and two levels of irrigation water salinity (0.5 - control and 4.5 dS m<sup>-1</sup>), with four replicates each. The level of 0.5 dS m<sup>-1</sup> corresponds to the local supply water and 4.5 dS m<sup>-1</sup>

was prepared by dissolving sodium chloride (NaCl), using the relation between electrical conductivity (dS m<sup>-1</sup>) and concentration of salts (mg L<sup>-1</sup>).

Initially, seeds of *P. gibertii* (BGP008), *P. cincinnata* (BGP290) and *P. edulis* (BRS 'Gigante Amarelo') were sown in polytubes in Vivato® substrate. After 90 days, when the plants had adequate height and stem diameter, they were grafted by the cleft method at the top. The scion used was *P. edulis*, BRS 'Gigante Amarelo' cultivar, in the three species mentioned above. After the grafting, the plants were transferred to a humid chamber for a period of seven days to avoid rapid dehydration of the scion and allow greater efficiency to obtain grafted seedlings (LIMA et al., 2017b).

### Experimental conditions

The plants were transplanted into polyethylene bags with a capacity of 3 dm<sup>3</sup>. The soil (sandy clay loam) used came from the experimental area of Embrapa Cassava and Fruits with the following physico-chemical characteristics in the 0-20 cm layer: pH in water = 5.2; P = 2 mg dm<sup>-3</sup>; K = 0.13 cmol<sub>c</sub> dm<sup>-3</sup>; Ca = 0.76 cmol<sub>c</sub> dm<sup>-3</sup>; Mg = 0.53 cmol<sub>c</sub> dm<sup>-3</sup>; Al = 0.3 cmol<sub>c</sub> dm<sup>-3</sup>; Na = 0.03 cmol<sub>c</sub> dm<sup>-3</sup>; H + Al = 3.19 cmol<sub>c</sub> dm<sup>-3</sup>; SB = 1.45 cmol<sub>c</sub> dm<sup>-3</sup>; CEC = 4.64 cmol<sub>c</sub> dm<sup>-3</sup>; V = 31%; OM = 8 g kg<sup>-1</sup>; total sand = 647 g kg<sup>-1</sup>; silt = 79 g kg<sup>-1</sup>; clay = 274 g kg<sup>-1</sup>. After 30 days, the grafted plants were transplanted into 40 dm<sup>3</sup> containers with 40 kg of the above mentioned soil. 50 g of FTE BR12 + 50 g of MAP + 50 g of potassium chloride were added to each container, which were protected with plastic (mulch) in order to avoid losses of water by evaporation and kept in the experimental area of Embrapa Cassava and Fruits.

At 15 days after transplanting, the plants were submitted to irrigation with saline water according to treatments. Irrigations were carried out on alternate days, the volume of water applied being calculated according to the following formula:  $VI = (VA - VD) / 0.9$ , where VI corresponds to the volume of water to be applied in the irrigation; VA to the volume of water applied in the previous irrigation; and VD to the volume of water drained in the previous irrigation. The index "0.9" corresponds to the factor that fixes the leaching fraction of 10%, in order to avoid excessive accumulation of salts in the soil. Drainage control was performed in each irrigation, and a collector was attached to the base of each container. After 60 days of transplanting, fertilization was carried out with FORTH Soluveis® (Nitrogen 19%, Phosphorus 19%, Potassium 19%, Boron 0.02%, Magnesium 0.6%), monthly, until

completion of the experiment, applying in each event 1 L plant<sup>-1</sup> of the solution containing 4 g L<sup>-1</sup>.

The plants were conducted on vertical plain wire guides, located at 2.0 m above the soil surface. Pruning of the main branch was carried out when it passed 10 cm of the wire and the pruning of the two lateral branches was performed when both reached 1.5 m in length.

### Physiological characteristics

At the beginning of flowering and fruiting (at 136 and 226 days after irrigation with saline water started, respectively), the plants were evaluated for CO<sub>2</sub> assimilation rate (*A*), transpiration (*E*), stomatal conductance (*gs*) and internal concentration of CO<sub>2</sub> (*Ci*) in fully expanded leaves between 09:00 and 12:00h under saturated radiation and ambient conditions of temperature and CO<sub>2</sub> concentration, utilizing a Infra-red Gas Analyser - IRGA (LCI System, ADC, Hoddesdon). The total chlorophyll (TC) was measured in the beginning of flowering with digital chlorophyll meter, and total water consumption (TWC) was estimated at the end of the study by the difference between water volume applied and drained during the crop cycle.

### Biometric characteristics

At 226 days after irrigation with saline water, passion fruit plants were evaluated for growth and development, by means of plant height (PH) from the point of grafting, number of leaves (NL), stem diameter (SD), leaf dry mass (LDM), stem dry mass (SDM) and root dry mass (RDM) per plant.

### Physico-chemical characteristics of fruits

At 226 days after irrigation with saline water, passion fruits were evaluated for fruit weight (FW), fruit length (FL), fruit diameter (FD), peel thickness (PT), peel weight (PW), weight of pulp (WP), total soluble solids (TSS), titratable acidity (TA) and the TSS/TA ratio, following the methodologies recommended by Jesus et al. (2017).

### Statistical analysis

The data were submitted to analysis of variance (ANOVA) by the F test ( $p \leq 0.05$ ) with further analysis of the interaction whenever it was significant. The quantitative factor, relative to the water salinity levels, and the species factor were analyzed by comparing means based on the Tukey test at 0.05 probability level. All analysis were performed using the Agricolae package implemented in the R program (R DEVELOPMENT CORE TEAM, 2016).

## RESULTS AND DISCUSSION

From the results of Table 1, it is observed that there was no interaction between the factors species x salinity, with a significant effect for the factor species only on the internal CO<sub>2</sub> concentration (*Ci*) in the flowering stage ( $p < 0.05$ ), while the factor salinity was significant for transpiration (*E*) and photosynthesis (*A*) in the flowering stage and *E* in the fruiting stage, and total chlorophyll (TC) and total water consumption (TWC).

**Table 1.** Summary of F test and means of gas exchange in passion fruit plants at 136 and 226 days after irrigation with saline water.

SV	Flowering (136 days)				Fruiting (226 days)				TC	TWC
	<i>Ci</i>	<i>E</i>	<i>gs</i>	<i>A</i>	<i>Ci</i>	<i>E</i>	<i>gs</i>	<i>A</i>		
Species (S)	*	ns	ns	ns	ns	ns	ns	ns	Ns	ns
Water salinity (WS)	ns	*	ns	*	ns	*	ns	ns	*	**
Interaction (S x WS)	ns	ns	ns	ns	ns	ns	ns	ns	Ns	ns
CV (%)	10.42	25.07	20.4	21.19	25.23	20.27	1.65	22.54	28.52	9.52
<i>P. edulis/Passiflora</i> spp.	Mean									
<i>P. cincinnata</i>	214.11ab	1.93a	0.11a	8.60a	185.93a	1.73a	0.08a	5.47a	45.33a	88.44a
<i>P. gibertii</i>	198.18b	1.77a	0.10a	8.42a	226.41a	1.96a	0.08a	5.91a	41.62a	85.37a
<i>P. edulis</i>	227.5a	2.11a	0.12a	8.03a	223.53a	1.80a	0.08a	5.04a	47.20a	91.93a
Water salinity (dS m <sup>-1</sup> )										
0.5	216.90a	2.18a	0.12a	9.13a	223.37a	2.0a	0.10a	5.80a	50.36a	100.15a
4.5	209.62a	1.70b	0.10a	7.57b	200.55a	1.65b	0.07a	5.17a	39.07b	77.01b

SV: source of variation. ns: not significant, \* significant ( $p \leq 0.05$ ) and \*\* significant ( $p \leq 0.01$ ) by the F test of the analysis of variance. Means followed by the same letter in the column do not differ by Tukey's test at 0.05 probability level. *Ci*: internal concentration of CO<sub>2</sub> ( $\mu\text{mol m}^{-2} \text{S}^{-1}$ ); *E*: transpiration ( $\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$ ); *gs*: stomatal conductance ( $\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$ ); *A*: CO<sub>2</sub> assimilation rate ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ ); TC: total chlorophyll ( $\mu\text{mol g}^{-1} \text{FM}$ ) and TWC: total water consumption (L plant<sup>-1</sup>). The *gs* data were transformed by the square root equation of  $y + 1.0 - \text{SQRT}(y + 1.0)$ .

The variation of the internal concentration of CO<sub>2</sub> ( $C_i$ ) was intrinsic to the species factor in the flowering stage of the grafted passion fruit, as no influence was observed on  $g_s$  and  $A$ . Different values of  $C_i$  are observed in the different rootstocks, being higher in auto-grafted *P. edulis*, with 227.5  $\mu\text{mol mol}^{-1}$  and lower in *P. edulis* / *P. gibertii*, with 198.18  $\mu\text{mol mol}^{-1}$ . In the fruiting stage there was no significant effect on  $C_i$  (Table 1), demonstrating that grafting exerts a pronounced effect on carbon metabolism in the flowering stage. Very high values of  $C_i$  in leaf mesophyll indicate that CO<sub>2</sub> is not being used for sugar synthesis by photosynthetic process, with accumulation of this gas, indicating that other non-stomatal factors are interfering in this process (LARCHER, 2006). These values are in agreement with those found by Freire et al. (2014), who verified  $C_i$  values of 229.4  $\mu\text{mol mol}^{-1}$  in *P. edulis* plants in the fruiting stage.

In different citrus rootstocks, Brito et al. (2016) also observed significant variations in the  $C_i$  of the plants, as observed in the present study, occurring different capacities of electron transport and gas exchange, to the detriment of the genetic variability observed in the species studied.

In the flowering stage of the grafted plants, the water salinity of 4.5 dS m<sup>-1</sup> affected the transpiration rate of plants (1.7 mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>), 22% less compared to the control (2.18 mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>) (Table 1), and this reduction in transpiration is a consequence of the effect of the salts on plant physiology (DIAS et al., 2016). Reduction in transpiration induced by water and salt stresses were also observed in *Jatropha curcas* by Silva et al. (2010), in *P. edulis* by Freire et al. (2014) and in *Ricinus communis* L. by Lima et al. (2017a). Leaf transpiration under conditions of salt stress is generally attributed to the partial closure of the stomata associated with the osmotic effect and ionic toxicity on plant metabolism (NEVES et al., 2009). Under these conditions, there is an imbalance between water absorption by the roots and the transpiration; therefore, partial closure of stomata is considered a strategy to avoid excessive dehydration or a consequence of the water imbalance in the epidermis of the leaves (RIBEIRO et al., 2009).

The net assimilation rate ( $A$ ) was compromised when the plants were irrigated with saline water (Table 1) in the flowering stage, being a sensitive phase (136 days after irrigation with saline water), with lower values (7.57  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ), whereas the plants under control treatment reached 9.13  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , with a 17.1% reduction. Salt stress reduces the net CO<sub>2</sub> assimilation and transpiration rate in glycophytes (FREIRE et al.,

2014), corroborating the responses obtained in the rate of net assimilation and transpiration in the flowering and fruiting stages (Table 1). Bezerra et al. (2018), evaluating *Psidium guajava* under salt stress, also observed a reduction of 18.35% per unit increase of ECw.

Salinity causes great disturbances in plant metabolism, and the first effects caused by excess salt are biophysical in nature, especially osmotic effects, restricting water transport, then quickly triggering a sequence of hormone-modulated reactions, which leads to reduced water absorption, transpiration and restriction of photosynthetic CO<sub>2</sub> assimilation in cells, among others. In the present study, ECw of 4.5 dS m<sup>-1</sup> reduced the  $A$  by 17%, due to osmotic effects on plant metabolism (SILVEIRA et al., 2016), indicating that some non-stomatal factor is interfering in this process.

Physiological disturbances in glycophytes caused by salt stress were verified by Cha-um and Kirdmanee (2011) and Freire et al. (2014), corroborating the results observed in passion fruit plants irrigated with saline water. The use of saline water in *Vigna unguiculata* and *Sorghum bicolor* also reduced the photosynthetic rate, as observed in the present study, attributed to the partial closure of the stomata (NEVES et al., 2009; SILVA et al., 2013; COELHO et al., 2018). Prolonged exposure to salts causes changes in the stomatal conductance of the plant, thereby limiting the influx of CO<sub>2</sub> into the mesophyll. In addition, high concentrations of ions have been reported as the cause of damage to enzyme and cell membrane structures, directly affecting photosynthesis (SILVA et al., 2011).

In the fruiting stage, the passion fruit plants under salt stress had reduced transpiration (1.65 mmol H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>), with inhibition of 17.5% compared to the control, a result similar to that found in the flowering stage and in the rate of assimilation ( $A$ ) (Table 1).

These results agree with those of Bezerra et al. (2018), who observed reductions in transpiration at 255 and 300 days after transplanting of *Psidium guajava* equal to 14.80 and 3.62% per unit increase in irrigation water salinity, respectively. The increment in soil salinity caused by the increase in irrigation water salinity reduces the osmotic potential of the soil solution, requiring from plants greater expenditure of energy to absorb water. In this situation, in an attempt to reduce water losses by transpiration, the plants decrease or deactivate part of their leaf area, hence reducing net photosynthesis and metabolic production (Freire et al., 2014).

Likewise, Nascimento et al. (2016) observed in vines under water deficit, reduction in photosynthesis, stomatal conductance and transpiration, while Suassuna et al. (2014) verified reductions in  $g_s$  and  $E$  in citrus rootstocks with water restriction. One of the effects of salt stress is the reduction in the availability of water to plants, which causes significant decreases in photosynthetic activity, transpiration and stomatal conductance, and this condition is mainly related to stomatal closure. Neves et al. (2009) and Silva et al. (2013), studying cowpea and Coelho et al. (2018) studying sorghum, also found that salt stress negatively affected plant transpiration. The observed reduction in transpiration rate with the increase in water salinity was due to the osmotic effect of salts around the roots and the possible accumulation of potentially toxic ions ( $\text{Na}^+$  and  $\text{Cl}^-$ ) in leaf tissues (BEZERRA et al., 2018).

The  $\text{EC}_w$  of  $4.5 \text{ dS m}^{-1}$  affected total chlorophyll (TC) and total water consumption (TWC) with reductions of 22.4 and 23.1% compared to the low-salinity treatment ( $\text{EC}_w = 0.5 \text{ dS m}^{-1}$ ), respectively (Table 1). This reduction in chlorophyll content is probably due to the effect of accumulated ions on chlorophyll biosynthesis in different fractions. The reduction in chlorophyll biosynthesis may be an acclimation response to salt stress in the context of energy savings and lower light energy uptake to avoid photooxidative stress (SILVEIRA et al., 2016). According to Munns and Tester (2008), the reduction in chlorophyll content

is the result of imbalance in physiological and biochemical activities promoted by the salt content in addition to that tolerated by crops. For these authors, the excess of salt stimulates the enzymatic activity of chlorophyllase, which degrades the photosynthesizing pigment molecules and induces the structural destruction of chloroplasts, also causing the imbalance and loss of activity of pigmentation proteins.

The reduction of the total water consumption in the saline treatment is attributed to the high salt concentration of the irrigation water, which reduces the water potential of the soil solution, causing a decrease in the water availability to the plant, thus reducing water consumption (DIAS et al., 2016), and consequently reducing transpiration and photosynthesis (Table 1). Similar results were also observed in *Passiflora edulis* by Freire et al. (2014), who found a 42.2% reduction in net photosynthesis between plants irrigated with low-salinity water and  $4.5 \text{ dS m}^{-1}$ , and Moura et al. (2017) observed a reduction of 4.48% in total water consumption per unit increase in irrigation water electrical conductivity ( $\text{EC}_w$ ), due to high salinity in irrigation water.

There was a significant effect of the factor species on NL ( $p < 0.05$ ) and LDM ( $p < 0.01$ ). However, salinity did not have a significant effect on any of the biometric variables evaluated, while species x salinity interaction for the NL and PH variables was significant at 0.05 probability level (Table 2).

**Table 2.** Summary of F test and means of the biometric variables of *P. edulis* grafted on three rootstocks of *Passiflora* spp. at 226 days after irrigation with saline water.

SV	PH (cm)	SD (mm)	NL	LDM (g)	SDM (g)	RDM (g)
Species (S)	ns	ns	*	ns	**	ns
Water salinity (WS)	ns	ns	ns	ns	ns	ns
Interaction (S x WS)	*	ns	*	ns	ns	ns
CV (%)	27.35	15.82	17.71	10.57	14.57	13.36
<i>P. edulis/Passiflora</i> spp.	Mean					
<i>P. cincinnata</i>	81.00a	6.75a	13.37c	4.86a	2.36ab	1.47a
<i>P. gibertii</i>	107.83a	5.61a	18.03b	5.04a	2.05b	1.43a
<i>P. edulis</i>	90.83a	6.80a	18.66a	5.05a	2.77a	1.47a
Water salinity ( $\text{dS m}^{-1}$ )						
0.5	99.25a	6.74a	17.19a	5.15a	2.49a	1.50a
4.5	87.20a	6.03a	16.19a	4.80a	2.30a	1.42a

SV: source of variation; ns: not significant, \* significant ( $p \leq 0.05$ ) and \*\* significant ( $p \leq 0.01$ ) by the test F. Means followed by the same letter in the column do not differ by Tukey test at 0.05 probability level. PH: plant height, SD: stem diameter, NL: number of leaves, LDM: leaf dry mass, SDM: stem dry mass and RDM: root dry mass.

For the interaction between species and water salinity, with regard to plant height, *P. edulis/P. edulis* had higher PH in the saline treatment ( $4.5 \text{ dS m}^{-1}$ ), with 45.5% superiority

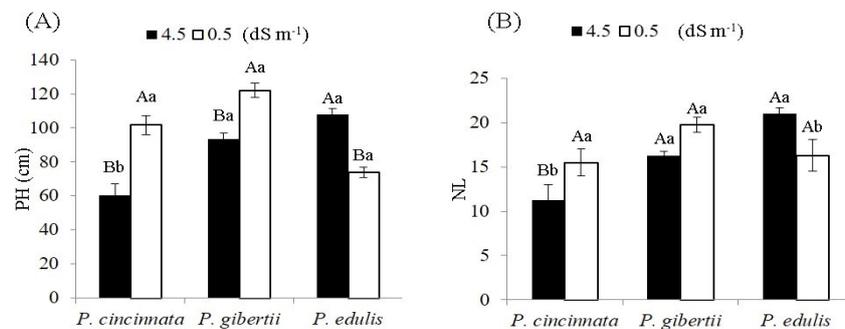
compared to the low-salinity treatment. However, the *P. edulis* plants grafted on *P. cincinnata* and *P. gibertii* in the saline treatment had reductions of

40.78 and 23.22%, respectively, in the height compared to the non-saline treatment (Figure 1A)

The reduction of PH as a function of the increase in salt concentration occurred due to the osmotic effect, which restricted the availability of water and nutrients, consequently compromising the physiological and metabolic processes for plants to adjust and produce vital substances, such as proteins, enzymes, nucleic acids and other organic assimilates, such as carbohydrates and sugars, essential for osmotic adjustment and growth (HEIDARI, 2009). This result corroborates the physiological and gas exchange results, where TWC, TC,  $E$  and  $A$  were compromised under high-salinity water (Table 1).

In relation to the species, *P. edulis* in the saline treatment indicated superiority in comparison to the others, and in the control treatment it had lower height. It is suggested that stress in

autografted plants of *P. edulis* activates mechanisms that minimize the effects of excess salts on the vital processes of plants, leading to higher PH in the saline treatment. This result shows that grafting is a valid strategy to avoid, at least partially, the ionic stress. Estañ et al. (2005) suggested that the effect of salt stress on tomato rootstock may vary according to the level of stress. These authors observed that Radja and Pera rootstocks had better physiological responses at higher salinity levels (50 and 75 mM NaCl); likewise, the autografted *P. edulis* in the present study had greater growth under salt stress. Moura et al. (2017) and Andrade et al. (2018) verified that *P. edulis* was significantly affected by reduction in PH with increased water salinity, while Souza et al. (2016) observed that the height of *P. edulis* under ECw of 4.0 dS m<sup>-1</sup> was not affected in sandy soil, that is, this species has mechanisms of tolerance to salinity.



**Figure 1.** A: Plant height (PH); B: number of leaves (NL) of *P. edulis* grafted on three rootstocks of *Passiflora* spp. submitted to salt stress at 226 days after irrigation with saline water.

Means followed by lowercase letters (species) for the same water salinity levels and uppercase letters (salinity) for the same species do not differ by Tukey's test ( $p \leq 0.05$ ).

In relation to the factor species, autografted *P. edulis* had the highest number of leaves, followed by *P. gibertii* rootstock with 39.56 and 34.85% of superiority in comparison to *P. cincinnata*, respectively (Table 2), and this result for *P. edulis* is in agreement with the  $C_i$  observed in Table 1.

Salts decrease the absorption of water and nutrients by plants and, when under salt stress, trigger the osmotic adjustment mechanism to maintain the turgidity of the cells, which results in a slower growth of the stressed plants (DEINLEIN et al., 2014, GUERZONI et al., 2014). For the species x water salinity interaction, there was a reduction in leaf production in *P. edulis*/*P. cincinnata* plants, when they were submitted to ECw of 4.5 dS m<sup>-1</sup>, decreasing the NL by 27.41% in comparison to the non-saline treatment (ECw = 0.5 dS m<sup>-1</sup>). Therefore, lower NL was observed in relation to the other combinations of grafting (Figure 1B). In autografted

plants of *P. edulis*, an opposite effect was observed, with an increase of 28.67% in the NL under high-salinity (4.5 dS m<sup>-1</sup>); however, when using *P. gibertii* as rootstock, no significant changes were observed at 0.05 probability level (Figure 1B).

Autografted *P. edulis* induced higher leaf production under conditions of high salinity, as verified in PH (Figure 1A), and grafting in this species attenuated the effect of the salts, being an alternative for passion fruit cultivation with saline water. In salinity studies with *Passiflora*, Moura et al. (2016a) found that *P. edulis* and *P. gibertii* are tolerant to salinity up to 4.7 dS m<sup>-1</sup> and *P. cincinnata* is moderately tolerant, corroborating the results of the present study. However, it is important to point out that the plant may exhibit a higher number of leaves and even have a smaller total leaf area due to salt stress.

The dry mass of the stem in the combination *P. edulis*/*P. edulis* was on average 35.12% higher compared to *P. edulis*/*P. gibertii* (Table 2), confirming the results of *Ci* and *NL* for the autografted plants of *P. edulis*. This response can be justified by the different morpho-anatomical characteristics of the species, which may have incompatibility between the xylem and phloem tissues when grafting is performed or due to the smaller diameter of the stem identified in this species, which may have influenced the dry mass of the stem of the scion (LIMA et al., 2017a). In addition, the grafting point may have affected the flow of hormones and other chemical compounds between rootstock and scion.

Marè, Mica and Cattivelli (2016) observed in autografted vines and different rootstocks that

plants retain their genetic identity, but some transcription factors, mRNAs, microRNAs, RNAs, peptides, and proteins are mobile in their vascular system and can pass through the graft union; further, it is suggested that cells at the interface of the graft can induce an immune response as an effect due to the presence of a graft belonging to other species, corroborating results obtained in the present study for the *P. gibertii* rootstock.

Table 3 shows the significance of the F test and the means of the physico-chemical attributes of the fruit quality. The species had a significant effect only on peel thickness (PT), total soluble solids (TSS) and ratio of total soluble solids to titratable acidity (TSS/TA) ( $p < 0.05$ ). There was no single effect for salinity and interaction between the two studied factors.

**Table 3.** Summary of F test and means for fruit quality of *P. edulis* grafted on *Passiflora* spp. subjected to salt stress

SV	FW	FL	FD	PT	PW	WP	TSS	TA	TSS/TA
Species (S)	ns	ns	ns	*	ns	ns	*	ns	*
Water salinity (WS)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Interaction (S x WS)	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	33.67	11.37	9.85	15.33	41.19	32.43	16.00	16.34	18.98
<i>P. edulis</i> / <i>Passiflora</i> spp.	Mean								
<i>P. cincinnata</i>	138.16a	79.93a	71.1a	7.03b	74.08a	62.12a	10.93b	3.15a	3.68b
<i>P. gibertii</i>	137.53a	81.02a	68.02a	7.06b	68.66a	69.32a	12.06ab	3.27a	3.76b
<i>P. edulis</i>	137.45a	84.67a	70.13a	8.55a	75.21a	65.68a	13.56a	2.97a	4.65a
Water salinity (dS m <sup>-1</sup> )									
0,5	146.24a	85.45a	71,80a	7.75a	77.28a	70.02a	12.79a	3.20a	4.20a
4,5	129.19a	78.30a	67.70a	7.35a	68.02a	61.40a	11.58a	3.06a	3.86a

SV: source of variation; ns: not significant and \* significant ( $p \leq 0.05$ ) by the F test of the analysis of variance. Means followed by the same letter in the column do not differ by Tukey's test at 0.05 probability level. FW: fruit weight - g; FL: fruit length - cm; FD: fruit diameter - mm; PT: peel thickness - mm; PW: peel weight - g; WP: weight of the pulp - g; TSS: total soluble solids - °Brix; TA: titratable acidity - % and TSS/TA: ratio of total soluble solids to titratable acidity.

The peel thickness of the autografted *P. edulis* was higher (8.55 mm) when compared to the other grafting combinations (Table 3). However, this result is lower than that found by Nascimento et al. (2015) which was 9.25 mm. The values of the *P. cincinnata* and *P. gibertii* rootstocks are similar to those obtained by Freire et al. (2010) (7.11 mm) in fruits of plants irrigated with saline water (4.5 dS m<sup>-1</sup>). Fruits of yellow passion fruit with lower peel thickness have a higher proportion of pulp (NASCIMENTO et al., 2015). However, the results presented here did not differ for the pulp mass as a function of the salinity and the rootstock used (Table 3).

Autografted *P. edulis* had the highest value of total soluble solids of fruits (13.56 °Brix), followed by *P. gibertii* rootstock (12.06 °Brix), while *P. cincinnata* showed the lowest value (10.39

°Brix). Nascimento et al. (2015) obtained maximum values of 12.78 and 11.29 °Brix in treatments with and without the use of biofertilizer + NPK, while Freire et al. (2010) and Dias et al. (2011), working with biofertilizer and irrigation with saline water (4.5 dS m<sup>-1</sup>), obtained fruits with values of 10.26 and 12.1 °Brix, respectively. However, no difference was observed between high and low salinity treatments in the present research, suggesting that the grafting technique may have had a positive influence on the quality of the fruits, reducing the deleterious effects of the salts on fruit quality, since they were not influenced by salinity.

The TSS values for autografting of *P. edulis* and *P. gibertii* rootstock are within the quality standards, in which the technical regulation for the establishment of the Identity and Quality Standards (IQS) for pulp of passion fruit of the Ministry of

Agriculture establishes the minimum value of 11 °Brix for the soluble solids content (RAIMUNDO et al., 2009). On the other hand, the mean value of TSS in the *P. cincinnata* rootstock is not suitable for pulp production (10.39 °Brix). Morais (2017) in the evaluation of fruits of the same species found values ranging from 9.07 to 11.90 °Brix. This low value of °Brix is perhaps directly related to the genetic characteristics of the species in interaction with the scion.

Autografted *P. edulis* showed a higher TSS/TA ratio, corroborating the characteristics of PT and TSS (Table 3) and also in the Ci (Table 1) and NL and SDM growth variables (Table 2). Moura et al. (2016b) found TSS/TA of 6.65 and 5.55 in *P. edulis* submitted to different doses of nitrogen, values higher than that found in the present study, but this superiority may be attributed to nitrogen fertilization. On the other hand, the values of TSS/TA indicate the palatability of the fruits because the balance between acids and sugars is more representative than the individual evaluation of these parameters (BRITO NETO et al., 2011).

In general, the salinity of the water affected only the gas exchange (rate of CO<sub>2</sub> assimilation and transpiration) and physiological variables (total chlorophyll and total water consumption), since the interaction between the factors (water salinity x species) only affected the growth in plant height and number of leaves. In relation to the species, autografted *P. edulis* stood out from the other species, with higher internal CO<sub>2</sub> concentration, number of leaves, stem dry mass, fruit peel thickness, total soluble solids of the pulp and TSS/TA ratio.

## CONCLUSIONS

The salinity of the irrigation water compromises the gas exchange (rate of CO<sub>2</sub> assimilation and transpiration) and physiological variables (total chlorophyll and total water consumption) in grafted *P. edulis*.

The interaction between the factors (water salinity x species) only affects the growth in plant height and number of leaves.

In relation to the species, autografted *P. edulis* stood out from the others, showing higher internal CO<sub>2</sub> concentration, number of leaves, stem dry mass, fruit peel thickness, total soluble solids of the pulp and TSS/TA ratio.

The autografted *P. edulis* under salt stress conditions develops vital mechanisms (TSS and TSS/TA), which attenuate the effects of salinity on the physico-chemical quality of the fruits.

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**RESUMO:** A produção de maracujazeiro enxertado é uma alternativa para adaptação das plantas a ambientes salinos. Objetivou-se avaliar o efeito do estresse salino na fisiologia, biometria e qualidade de frutos de *P. edulis* enxertado em espécies de *Passiflora* spp. O delineamento utilizado foi inteiramente casualizado, em esquema fatorial 3 x 2, sendo três espécies de *Passiflora* (*P. edulis*, *P. gibertii* e *P. cincinnata*) tendo como copa *P. edulis* e dois níveis de salinidade de água de irrigação (0,5 – testemunha e 4,5 dS m<sup>-1</sup>), com quatro repetições. A salinidade da água compromete as trocas gasosas (taxa de assimilação de CO<sub>2</sub> e transpiração) e variáveis fisiológicas (clorofila total e consumo hídrico total) em *P. edulis* enxertado. A interação entre os fatores (salinidade da água x espécie) compromete apenas o crescimento em altura de plantas e número de folhas. Em relação às espécies, o *P. edulis* auto enxertado se destaca em relação as demais espécies apresentando maior concentração interna de CO<sub>2</sub>, número de folhas, massa seca de caule, espessura da casca do fruto, sólidos solúveis totais (SST) da polpa e razão sólidos solúveis totais por acidez titulável (SST/AT). O *P. edulis* auto enxertado sob condições de salinidade, desenvolve mecanismos vitais (SST e SST/AT), que atenuam os efeitos do estresse salino na qualidade físico-química dos frutos.

**PALAVRAS-CHAVE:** Enxertia. *Passiflora cincinnata*. *Passiflora gibertii*. Salinidade. Trocas gasosas.

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