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Scientific Article

Quality of yellow passion fruit seedlings under saline water irrigation and salicylic acid concentrations

Qualidade de mudas de maracujazeiro-amarelo sob irrigação com águas salobras e concentrações de ácido salicílico

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ABSTRACT - The objective of this study was to evaluate the quality of 'BRS Gigante Amarelo' passion fruit seedlings irrigated with brackish waters under salicylic acid application. The experiment was conducted under conditions of protected environment (screened) in the experimental area of the Federal Rural University of the Semi-arid Region (UFERSA), Multidisciplinary Campus of Caraúbas, RN, Brazil, in the period from August to November 2022, in a randomized block experimental design and analyzed in a 4 x 4 factorial scheme, with four replicates and one plant per plot, with treatments consisting of electrical conductivity of irrigation water - ECw (0.5, 1.4, 2.3 and 3.2 dS m^{-1}) and concentrations of salicylic acid - SA (0.0, 1.5, 3.0, and 4.5 mM L^{-1}). Electrical conductivity of irrigation water up to 3.2 dS m^{-1} does not affect the absolute growth, photosynthetic rate and quality of 'BRS Gigante Amarelo' passion fruit seedlings; ECw from the average value of 1.3 dS m^{-1} affects stomatal conductance, transpiration, internal CO_2 concentration and root fresh and dry mass production. Foliar application of salicylic acid does not mitigate the effect of salt stress from irrigation water on the production of yellow passion fruit seedlings; however, the average concentration of 3.15 mM L^{-1} promotes greater absolute and relative growth, shoot fresh and dry mass and quality of seedlings. SA concentration of 1.5 mM L^{-1}, associated with ECw of 1.0 dS m^{-1}, is recommended for the production of "BRS Gigante Amarelo" passion fruit seedlings.

Keywords: *Passifloraceae*. Salt stress. Phytohormone.

RESUMO - Objetivou-se com esta pesquisa avaliar a qualidade de mudas de maracujazeiro 'BRS Gigante Amarelo' irrigadas com águas salobras sob aplicação de ácido salicílico. O experimento foi conduzido sob condições de ambiente protegido (telado) na área experimental da Universidade Federal Rural do Semiárido (UFERSA), Campus Multidisciplinar de Caraúbas, RN, no período de agosto a novembro de 2022, instalado em delineamento experimental de blocos ao acaso e analisados no esquema fatorial 4 x 4, com quatro repetições e uma planta por parcela, cujos tratamentos foram compostos do fator condutividade elétrica da água de irrigação - CEa (0,5; 1,4; 2,3 e 3,2 dS m^{-1}), com concentrações de ácido salicílico - AS (0,0; 1,5; 3,0; e 4,5 mM L^{-1}). A condutividade elétrica da água de irrigação de até 3,2 dS m^{-1} não afeta o crescimento absoluto, a taxa fotossintética e a qualidade de mudas de maracujazeiro 'BRS Gigante Amarelo'. A CEa do valor médio 1,3 dS m^{-1} afeta a condutância estomática, transpiração, concentração interna de CO_2 e a produção de fitomassa fresca e seca da raiz. A aplicação foliar de ácido salicílico não mitiga o efeito do estresse salino da água de irrigação na produção de mudas de maracujazeiro-amarelo, entretanto, concentração média de 3,15 mM L^{-1} promove maior crescimento absoluto e relativo, fitomassa fresca e seca da parte aérea e qualidade de mudas. A concentração de 1,5 mM L^{-1} de AS, associada a uma CEa de 1,0 dS m^{-1}, é recomendada para a produção de mudas de maracujá "BRS Gigante Amarelo".

Palavras-chave: *Passifloraceas*. Estresse salino. Fitormônio.

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INTRODUCTION

The genus Passiflora is present throughout Tropical America and has a large number of species, with emphasis on the species *Passiflora edulis* Sims, which has high economic and social relevance. Brazil stands out as the largest producer and exporter in the world, with production of 690.364 thousand tons of passion fruit in 2020 (FALEIRO; JUNQUEIRA; COSTA, 2016; IBGE, 2021).

The use of saline waters in irrigation is an alternative found in regions with a shortage of non-brackish water. Plants grown in water with a high salinity level are most often induced to experience severe osmotic tensions, which leads to greater absorption of sodium by their roots, causing changes in the osmotic balance and toxicity of ions, related to the accumulation of reactive oxygen species (ROS) by plants (SUN et al., 2020).

The water salinity level that can compromise plants depends on some factors such as: species, genotype, phenological stage, type and concentration of ions, cultivation strategies, irrigation management and fertilization. According to Ayers and Westcot (1999), passion fruit is sensitive to salinity, having a threshold of 1.3 dS m^{-1}, so higher salinity levels can compromise its production.

Lima et al. (2021) evaluated the growth of passion fruit seedlings 'BRS

Rubi do Cerrado' irrigated with ECw ranging from 0.3 to 3.5 dS m^{-1} and verified the reduction in stem diameter with the increase in ECw. Similarly, Silva Neta et al. (2021) observed that salinity from 0.3 dS m^{-1} reduced leaf area, plant height and stem dry mass of ‘BRS Rubi do Cerrado’ passion fruit plants. Andrade et al. (2022), in their study carried out with yellow passion fruit irrigated with saline water, found a reduction in biomass under salinity of 1.4 dS m^{-1}.

Salicylic acid (SA) appears as an alternative in the attenuation of water and salt stress on plants, since it performs various functions in their metabolism and is involved in physiological processes such as stomatal flow, photosynthesis, respiration, ion absorption and floral induction (ZRIG et al., 2021).

Foliar spraying with SA has been shown to be efficient in the acclimatization of plants subjected to salt stress, as observed by Torres et al. (2022) in their study on the induction of tolerance to salicylic acid in sour passion fruit irrigated with waters of different cationic compositions. The authors found increases of 26.88% in the synthesis of chlorophyll b, with the application of 3.0 mM SA. Positive results were also found in cowpea (JALES FILHO et al., 2022) and soursop (SILVA et al., 2022). In this context, this study aimed to evaluate the application of SA as attenuator of salt stress from irrigation water on the production of ‘BRS Gigante Amarelo’ passion fruit seedlings under the northeastern semi-arid conditions.

MATERIAL AND METHODS

The experiment with yellow passion fruit crop was conducted from August to November 2022 under conditions of protected environment (screened), in an experimental area at the Multidisciplinary Campus of Caraúbas of the Federal Rural University of the Semi-arid Region (UFERSA), in the municipality of Caraúbas, RN, Brazil, located at 05°47’33” S, 37°33’24” W and altitude of 144 m. According to Alvares et al. (2013), the area is located in the semi-arid region, with average annual precipitation of 673.9 mm and maximum temperature of 32 ºC.

The following treatments were adopted: four levels of electrical conductivity of irrigation water - ECw (0.5, 1.4, 2.3 and 3.2 dS m^{-1}) associated with four concentrations of salicylic acid - SA (0.0, 1.5, 3.0, and 4.5 mM L^{-1}), in the production of ‘BRS Gigante Amarelo’ passion fruit seedlings. The experiment was conducted in a randomized block design, in a 4 x 4 factorial arrangement, with 4 replicates, and one plant per plot. As a plant material, the passion fruit cultivar ‘BRS Gigante Amarelo’, which stands out in terms of yield and fruit quality, was studied.

Sowing was carried out in 1.150-L plastic bags, containing holes at the base to allow free drainage, which were filled with sandy loam soil material, representative of the region of Caraúbas, RN, collected at 0-20 cm depth and with addition of 5%, on a volume basis, of aged cattle manure. The bags were arranged on wooden pallets at 15 cm height. In each bag, 3 seeds were sown at 1.0 cm depth and, after stabilization of seedling emergence, thinning was performed, leaving only the most vigorous seedling. According to the methodologies proposed by Teixeira et al. (2017), the physical and chemical characteristics of the substrate used in the experiment were analyzed at the beginning of the experiment (Table 1).

Table 1. Physical and chemical characteristics of the substrate used for sowing of ‘BRS Gigante Amarelo’ passion fruit seedlings.

Sand	Silt	Clay	Textural classification	ECse dS m^{-1}	pHse H_2O	OM g kg^{-1}
g kg^{-1}						
446	411	143	Loam	0.68	6.03	37

P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	(H +Al)	SB	T	CEC	V	M	ESP
mg dm^{-3}	cmol$_c$ dm^{-3}									%		
134.2	0.87	0.15	17.11	1.14	0.0	0.58	19.27	19.27	19.27	97	0	1

OM – Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 mol L^{-1} KCl at pH 7.0; Na^+ and K^+ extracted with 1 mol L^{-1} NH_4OAc at pH 7.0; Al^{3+} and (H^+ + Al^{3+}) extracted with 1 mol L^{-1} CaOAc at pH 7.0; ECse – electrical conductivity of the substrate saturation extract at 25 °C; pHse – pH of the substrate saturation extract.

The brackish waters were obtained from the dilution of sodium chloride (NaCl), calcium chloride ($CaCl_2.2H_2O$) and magnesium chloride ($MgCl_2.6H_2O$) salts in local-supply water (0.5 dS m^{-1}), in the proportion of 7:2:1, a proportion commonly found in the waters of northeastern Brazil (MEDEIROS et al., 2003), following the relationship between ECw and salt concentration (mmol$_c$ L^{-1} = EC x 10) (RICHARDS, 1954).

After preparation, the waters were stored in 90-L plastic containers, one for each ECw level studied, properly protected to avoid evaporation, entry of rainwater and contamination with materials that could compromise their quality. These waters were changed every 20 days, and the salt concentrations were homogenized before irrigation. ECw assessment was carried out at the beginning and end of the experiment. The salinity levels studied here were chosen based on the study conducted by Silva et al. (2018). Salicylic acid concentrations were obtained by dissolution in 30% ethyl alcohol (95.5%), as it is a substance of low solubility in water at ambient temperature. SA levels were established according to a study conducted by Abbaszadeh et al. (2020).

Applications of SA concentrations started at 30 days after sowing (DAS) and were always performed at 5:00 p.m., with the aid of a manual sprayer, with capacity of 350 mL, using physical barriers to avoid interference between treatments. Application intervals were equal to 7 days, totaling 7 applications of salicylic acid at the end of the experiment: for the first three sprays, the volume applied was 3 mL per plant, or time of 3 s, and from the fourth week, the volume increased to 8 mL per plant, or time of 8 s. As a way to measure the volume of SA spraying on plants, the amount of mL corresponding to each spray of the sprayer was measured in the laboratory with the aid of a beaker and a graduated pipette.

The soil was maintained with moisture close to field capacity throughout the experimental period. Until 34 DAS, the seedlings were irrigated with local-supply water (0.5 dS m^{-1}), twice a day, and after this period, they were irrigated using the waters of the different treatments. The volume applied in each irrigation was determined based on the drainage lysimetry process, using a sample of bags of each treatment, with weekly evaluation according to the state of plant growth, and daily applying the evapotranspired volume of each type of water, in order to raise the soil moisture content to the level of field capacity.

Nitrogen fertilization was performed at 38 DAS, after dilution of 53.76 g of urea, which represents 0.0618 g of N (Nitrogen), in 20 L of water, by placing 50 mL in each bag. Potassium fertilization was carried out via fertigation, in which 16 g of potassium chloride fertilizer were applied, diluted in 10 L of water. During the experiment, manual weeding was carried out to control interspecific competition for water and nutrients, favoring the development of the seedlings, as well as phytosanitary control.

To analyze the effect of treatments on yellow passion fruit, the absolute growth rates - AGR (Equation 1) and relative growth rates - RGR (Equation 2) of plant height, stem diameter and leaf area were evaluated according to Benincasa (2003) in the 49-82 DAS period.

$$AGR_x = \frac{(X_2 - X_1)}{(t_2 - t_1)} \quad (1)$$

$$RGR_x = \frac{\ln X_1 - \ln X_2}{t_2 - t_1} \quad (2)$$

where:

AGR_x - Absolute growth rate in plant height (cm day^{-1}), stem diameter (mm day^{-1}) or leaf area (cm^2 day^{-1});

RGR_x - Relative growth rate in plant height (cm cm^{-1} day^{-1}), stem diameter (mm mm^{-1} day^{-1}) or leaf area (cm^2 cm^{-1} day^{-1});

X_1 and X_2 – plant height, stem diameter or leaf area at times t_1 and t_2;

T_2 and T_1 – time interval between observations of plant height, stem diameter or leaf area, in days.

Physiological evaluations were performed at 82 DAS, at 9:00 a.m., on the third leaf of the plant, counted from the apex, on which the following parameters were determined: CO_2 assimilation rate (*A*) (µmol CO_2 m^{-2} s^{-1}), stomatal conductance (*gs*) (mol H_2O m^{-2} s^{-1}), transpiration (*E*) (mol H_2O m^{-2} s^{-1}), and intercellular CO_2 concentration (Ci) (µmol m^{-2} s^{-1}) measured with an LCpro infrared gas analyzer (IRGA) with constant light source of 1,200 µmol photons m^{-2} s^{-1} and CO_2 concentration of 370 µmol mol^{-1}.

At the end of the experiment at 82 DAS, shoot fresh mass (SFM) and shoot dry mas (SDM) were determined by weighing the leaves and stem of each plant, and then root fresh mass (RFM) and root dry mass (RDM) were determined by weighing the roots (Figures 1A, 1B and 1C). Shoot dry mass and root dry mass (g) were obtained after drying the materials in a forced air circulation oven at 65 ºC until they reached constant weight. The overview of the experiment is in Figure 1D.

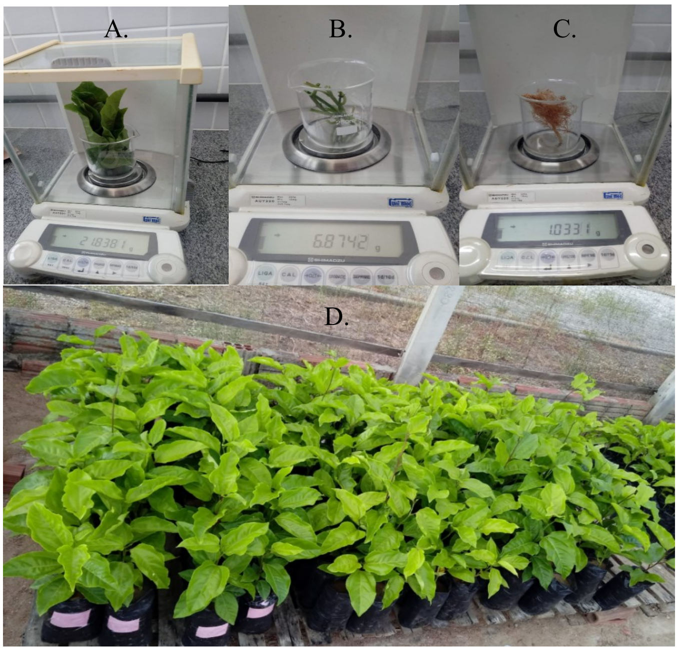


Figure 1. Determination of shoot fresh mass - SFM (A and B), root dry mass -RDM (C) and overview of the experiment (D) of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water – ECw (A) and different concentrations of salicylic acid (B), at 82 DAS.

Seedling quality was evaluated using the Dickson Quality Index (DQI), according to the formula of Dickson, Leaf and Hosner (1960), Equation 3:

$$DQI = \left[\frac{TDM}{PH/SD}\right] + \left[\frac{SDM}{RDM}\right] \qquad (3)$$

where:
TDM - total dry mass (g) obtained by the sum of SDM + RDM;
PH - plant height (cm);
SD - stem diameter (mm);
SDM - shoot dry mass (g);
RDM - root dry mass (g);

The means of the variables were subjected to analysis of variance, with F test (0.01>p<0.05 probability levels) and, when significant, regression analysis was applied for the levels of electrical conductivity of irrigation water and salicylic acid concentrations, using the statistical program SISVAR/UFLA (FERREIRA, 2019).

RESULTS AND DISCUSSION

Based on the analysis of variance summary (Table 2), there was a significant effect only of the SA concentrations factor on the absolute growth rates of plant height (AGR_{PH}), stem diameter (AGR_{SD}) and leaf area (AGR_{LA}) of 'BRS Gigante Amarelo' passion fruit seedlings in the period from 49 to 82 DAS. In relation to the relative growth rate, there was a significant effect of the individual factors (Salinity levels and SA concentrations) only on the relative growth rate of plant height (RGR_{PH}).

Table 2. Summary of the analysis of variance for absolute growth rates (AGR) and relative growth rates (RGR) of plant height (PH), stem diameter (SD) and leaf area (LA), of 'BRS Gigante Amarelo' passion fruit seedlings as a function of different salinity levels of irrigation water (SL) and concentrations of salicylic acid (SA), in the period from 49 to 82 DAS.

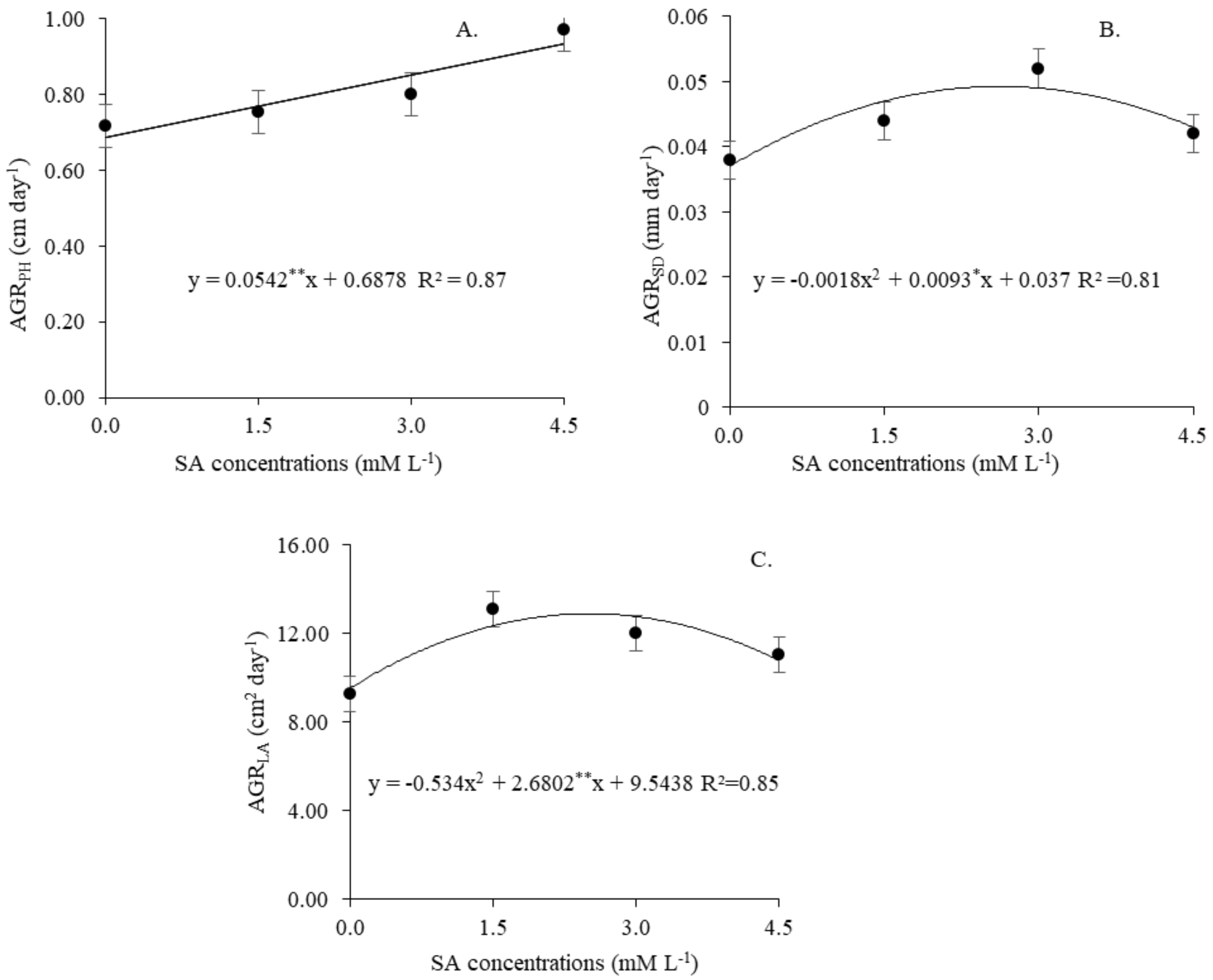
Source of Variation	Mean Square					
	AGR_{PH}	AGR_{SD}	AGR_{LA}	RGR_{PH}	RGR_{SD}	RGR_{LA}
Salinity Levels (SL)	0.052^{ns}	0.00014^{ns}	24.586^{ns}	0.000026^{*}	0.0002^{ns}	0.00070^{ns}
Linear Reg.	0.064^{ns}	0.00034^{ns}	0.230^{ns}	0.000001^{ns}	0.00050^{ns}	0.0000^{ns}
Quadratic Reg.	0.091^{ns}	0.000075^{ns}	23.608^{ns}	0.000078^{*}	0.00001^{ns}	0.000099^{ns}
SA Concentrations	0.153^{**}	0.00041^{*}	31.305^{**}	0.000030^{*}	0.00023^{ns}	0.0037^{ns}
Linear Reg.	0.398^{**}	0.00021^{ns}	10.361^{ns}	0.000083^{*}	0.00010^{ns}	0.00023^{ns}
Quadratic Reg.	0.052^{ns}	0.00083^{*}	69.286^{**}	0.000004^{ns}	0.00052^{ns}	0.00067^{ns}
Interaction (SL x SA)	0.058^{ns}	0.000098^{ns}	9.092^{ns}	0.000028^{ns}	0.00006^{ns}	0.000040^{ns}
Block	0.054^{ns}	0.00019^{ns}	7.510^{ns}	0.00011^{**}	0.00038^{ns}	0.00021^{ns}
CV(%)	21.99	31.08	22.25	14.21	31.94	32.63

ns, **,* respectively not significant, significant at $p \leq 0.01$ and $p \leq 0.05$, by the F test; CV = coefficient of variation.

According to the regression equation (Figure 2A), the increase in SA concentrations positively influenced the absolute growth rate of plant height of passion fruit, causing an increment of 7.88% per unit increase in SA concentration, that is, an increase of 35.46% in AGR_{PH} between the highest (4.5 mM L^{-1}) and the lowest (0 mM L^{-1}) concentration of SA. This probably occurred because salicylic acid acts in the regulation of the cell cycle and secondary metabolism of the plant, where it accumulates mainly in the shoots, allowing greater increment (NAPOLEÃO et al., 2017).

The use of salicylic acid significantly favored the absolute growth rates of stem diameter and leaf area, in the period from 49 to 82 DAS (Table 2), and according to the regression equation (Figures 2B and 2C) the quadratic model fitted best to the data, with maximum values of 0.05 mm day^{-1} for AGR_{SD} and 12.91 cm^2 day^{-1} for AGR_{LA} in plants subjected to SA concentration of 2.5 mM L^{-1}. This behavior is probably due to the fact that salicylic acid acts in the process of cell division, through its action on phytohormones, in addition to its participation in the synthesis of glycine-betaine, which confers the plant osmoprotection, maintaining the turgor level necessary for cell growth. However, it was possible to observe a small reduction in leaf area, which is a crucial factor in carrying out photosynthesis, as it is through the leaves that the plant absorbs sunlight and CO_2 and transforms light energy into chemical energy. The reduction in leaf area can cause a decrease in transpiration, as observed in the present study (Figures 5A and 6A), affecting the absorption of water and nutrients by the plant (TAIZ et al., 2017).

The increase in irrigation water salinity caused a significant effect on the relative growth rate of plant height in the period from 49 to 82 DAS, and according to the regression equation (Figure 3A) the quadratic model fitted to the values, with the best response of RGR_{PH} (0.029 cm cm^{-1} day^{-1}) in plants under ECw of 1.70 dS m^{-1}. The reduction in RGR_{PH} is possibly due to the partial closure of the stomata, triggering changes in several physiological processes, in addition to possible damage to the photosynthetic apparatus, hence reducing the expansion and growth of the plant (BONACINA et al., 2022).



Vertical bars represent the standard error. **,* - Significant at $p \leq 0.01$ and $p \leq 0.05$, respectively, by the F test. CV = Coefficient of variation.

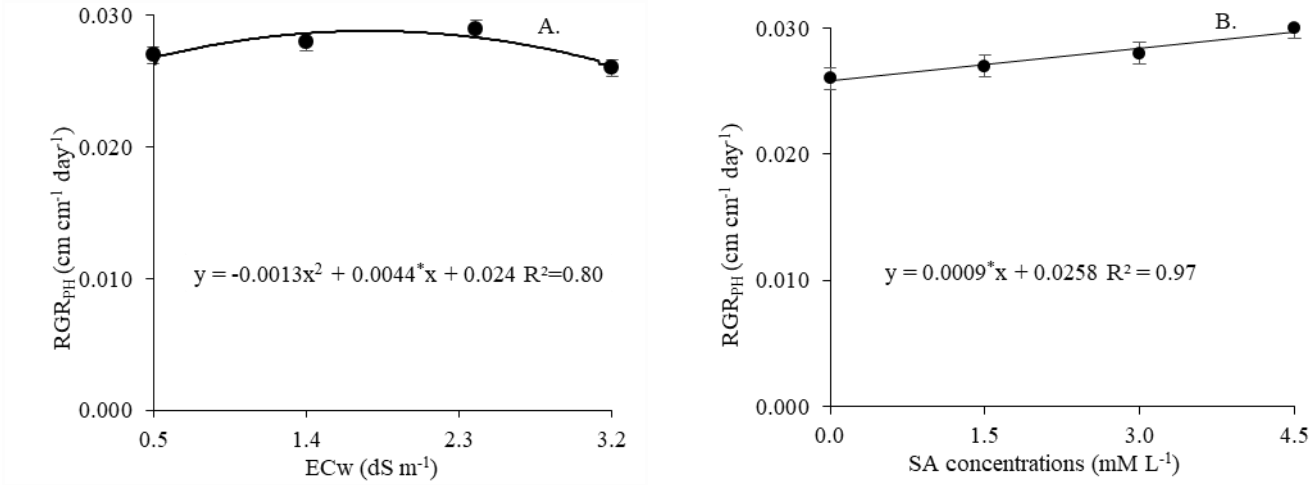
Figure 2. Absolute growth rates of plant height - AGR_{PH} (A), stem diameter - AGR_{SD} (B) and leaf area - AGR_{LA} (C) of 'BRS Gigante Amarelo' passion fruit seedlings as a function of different concentrations of salicylic acid, in the period from 49 to 82 DAS.

Under stress conditions, the soil matric potential is reduced, as a result of which plants have compromised water absorption. The increase in soil osmotic pressure can reach tensions at which plants do not have enough energy for suction to overcome the soil potential, so there is a reduction in cell division and elongation, which results in a decrease in plant height (TAIZ et al., 2017).

As observed for the absolute growth rate of plant height (Figure 2A), salicylic acid concentrations promoted a linear unit increase of 3.49% in the relative growth rate of plant height (Figure 3B), with an increase of 15.70% for plants subjected to the SA concentration of 4.5 mM L^{-1} compared to those that did not receive salicylic acid.

According to the results of the analysis of variance (Table 3), there were significant effects of the interaction between the factors (SL x SA) on transpiration (E) and intercellular CO_2 concentration (Ci) of 'BRS Gigante Amarelo' passion fruit seedlings at 82 DAS. The single factors salinity levels of irrigation water (SL) and salicylic acid concentrations (SA) also had significant effect on stomatal conductance.

The increase in salinity of irrigation water significantly influenced ($p \leq 0.01$) the stomatal conductance of passion fruit seedlings at 82 DAS (Table 3), with a quadratic behavior in the data according to the regression equation (Figure 4A), whose maximum value (0.15 mol H_2O m^{-2} s^{-1}) was obtained in plants under ECw of 1.50 dS m^{-1}, with decrease from this point on, and the lowest value (0.10 mol H_2O m^{-2} s^{-1}) was obtained with ECw of 3.2 dS m^{-1}. This behavior of *gs* may be related to the process of acclimatization of plants because, under salt stress conditions, they partially close their stomata to reduce transpiration and consequently water loss. By closing their stomata, they increase stomatal resistance to the flow of water vapor from the leaves to the external atmosphere; this is a plant strategy to maintain the water potential in the leaves and avoid dehydration, consequently there is a restriction of normal flow of CO_2 (TAIZ et al., 2017).



Vertical bars represent the standard error. * - Significant at $p \leq 0.05$ by the F test. CV = coefficient of variation.

Figure 3. Relative growth rates of plant height - RGR_{PH} of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water - ECw (A) and different concentrations of salicylic acid (B) in the period from 49 to 82 DAS.

Table 3. Summary of the analysis of variance for CO_2 assimilation rate (*A*), stomatal conductance (*gs*), transpiration (*E*) and intercellular CO_2 concentration (Ci) of 'BRS Gigante Amarelo' passion fruit seedlings as a function of different salinity levels of irrigation water (SL) and concentrations of salicylic acid (SA) at 82 DAS.

Source of Variation	Mean Square			
	A	Gs	E	Ci
Salinity Level (SL)	21.88^{ns}	0.06**	3.69**	630.41*
Linear Reg.	21.42^{ns}	0.009**	2.95**	53.20^{ns}
Quadratic Reg.	3.140^{ns}	0.009**	7.95**	1788.52*
SA concentrations	17.68^{ns}	0.008**	1.77**	1629.69*
Linear Reg.	0.690^{ns}	0.010**	2.97**	1201.54*
Quadratic Reg.	12.38^{ns}	0.008**	1.67**	3519.19**
Interaction (SL x SA)	10.57^{ns}	0.001^{ns}	0.34*	1058.77*
Block	9.60^{ns}	0.002^{ns}	1.78**	240.81^{ns}
CV(%)	15.57	23.22	15.22	12.25

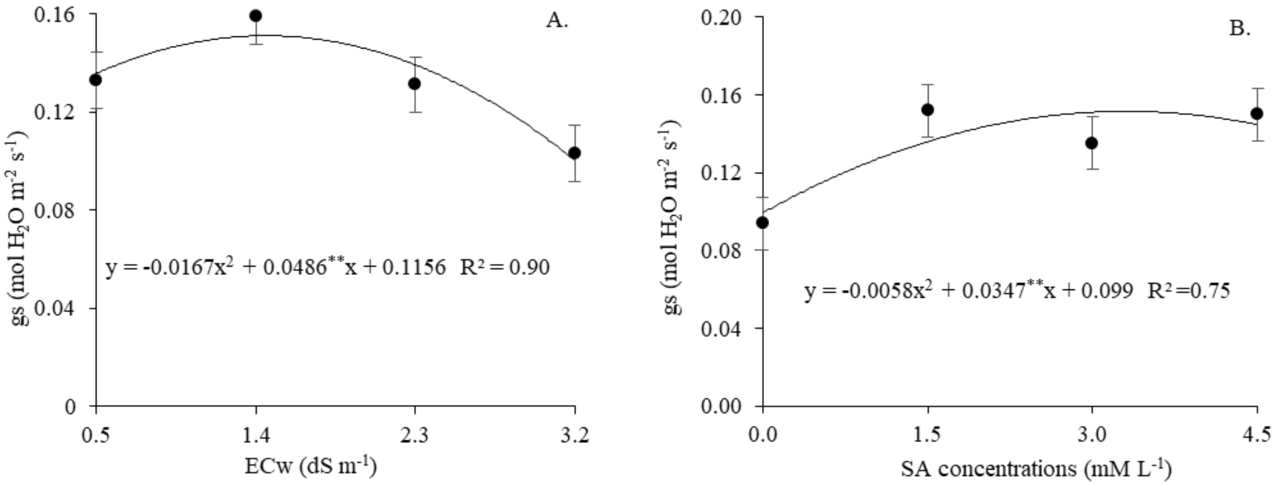
ns, **,* respectively not significant, significant at $p \leq 0.01$ and significant at $p \leq 0.05$ by the F test. CV = coefficient of variation.

The concentrations of salicylic acid significantly influenced *gs* (Table 3) and, according to the regression equation (Figure 4B), the quadratic model fitted to the data, with the highest value (0.14 mol H_2O m^{-2} s^{-1}) obtained with SA concentration of 2.0 mM L^{-1}. This effect of SA on *gs* is probably related to its action as a mitigator of osmotic and ionic stress, which promotes an increase in the concentration of organic solutes for plant osmoregulation (FARHANGI-ABRIZ; GHASSEMI GOLEZANI, 2018). The results found in this study corroborate the findings by Silva et al. (2021), who obtained a 7.88% increase in gs, using a concentration of 1.4 mM L^{-1} SA in soursop crop.

There was a significant effect of the interaction between factors (water salinity level and SA concentrations) on transpiration (E), with best fit of the quadratic regression model to the data (Figure 5A), whose maximum value (3.65 mol H_2O m^{-2} s^{-1}) was obtained at salinity of 1.60 dS m^{-1} and SA concentration of 3.0 mM L^{-1}. It is possible to observe a decrease in the transpiration rate of plants under ECw of 3.2 dS m^{-1}, possibly due to stomatal limitation, because under stress conditions the plant reduces its gas exchange between the leaves and the environment as a way of adapting to the imposed condition (TAIZ et al., 2017).

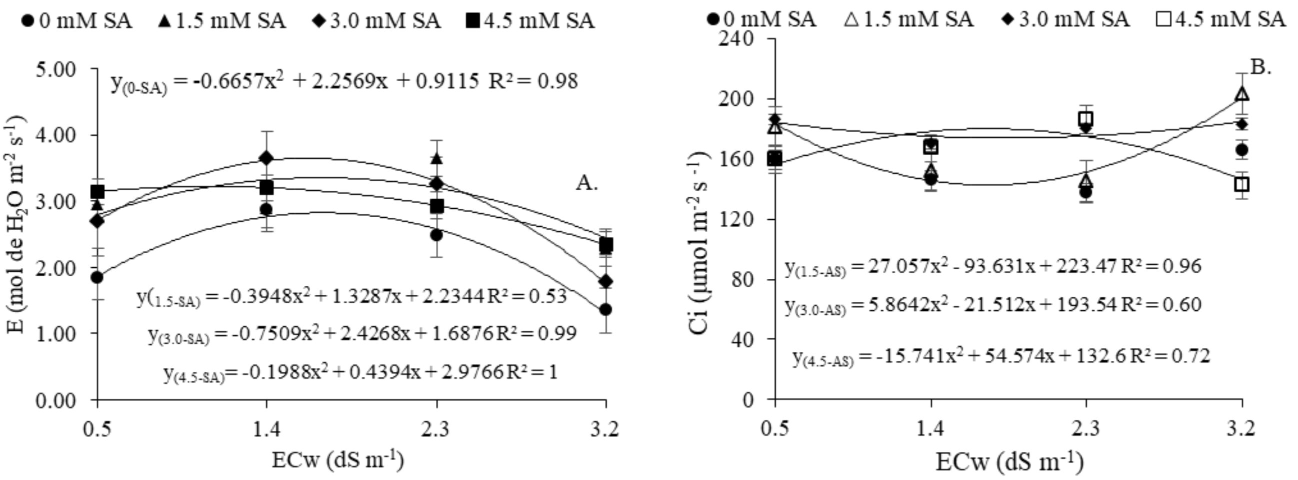
There was significant effect of the interaction ($p \leq 0.05$) between the studied factors (SL x SA) on the intercellular CO_2 concentration, with best fit of the quadratic regression model (Figure 5B), and the maximum Ci value (223.47 µmol m^{-2} s^{-1}) was obtained in plants under SA concentration of 1.5 mM L^{-1} and ECw of 0.5 dS m^{-1}. However, it was observed that Ci increased in plants under salinity of 3.2 dS m^{-1}, a behavior that is inverse to that observed in stomatal conductance (Figure 4A). The increase in Ci promoted by the increase in ECw may be related to possible changes in the photosynthetic apparatus, affecting the activity of the enzyme ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCO), which prevents the synthesis of CO_2.

The increase in Ci also indicates the lack of CO_2 flow to synthesize organic compounds, so there is an accumulation of CO_2 in the substomatal cavity (LARCHER, 2004). Despite the stress caused by salinity in gs, E and Ci, it can be seen in Table 3 that the levels studied here did not influence photosynthesis, as well as AGR_{PH}, AGR_{SD} (Figures 2A and 2B), and shoot dry mass (Figure 7A), so the passion fruit seedlings can be considered tolerant to salt stress, as observed by Moura et al. (2016).



Vertical bars represent the standard error. **- Significant at $p \leq 0.01$ by the F test. CV = coefficient of variation.

Figure 4. Stomatal conductance – *gs* of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water – ECw (A) and different concentrations of salicylic acid (B), at 82 DAS.

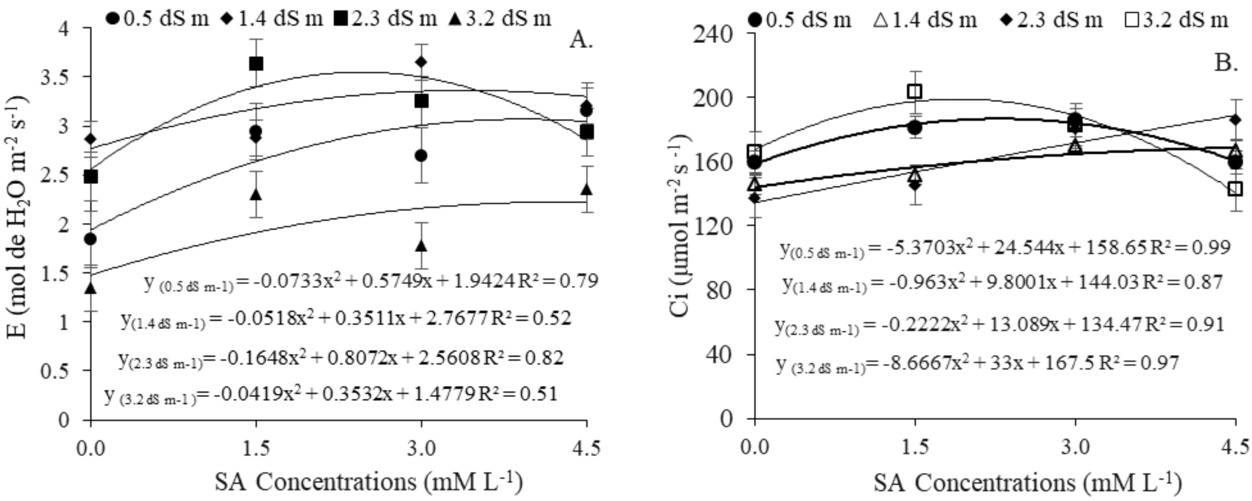


Vertical bars represent the standard error. * - significant at $p \leq 0.05$ by the F test. CV = coefficient of variation.

Figure 5. Transpiration (A) and intercellular CO_2 concentration (B) of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water – ECw and different concentrations of salicylic acid – SA, at 82 DAS.

Transpiration had a significant response regarding the decomposition of the interaction between ECw and SA, with fit of the quadratic model in the regression equation, with a maximum value of 3.55 mol H_2O m^{-2} s^{-1}, at ECw of 2.3 dS m^{-1} and SA concentration of 2.5 mM L^{-1} (Figure 6A). The pattern observed in the analysis of ECw considering each SA concentration was similar to that observed in Figure 5A; with increased salinity, there is a reduction in transpiration. This fact probably occurred due to strategies employed by plants, which, under stress conditions, partially close their stomata in order to avoid water loss. Another factor is due to the accumulation of salts in the root zone by plants under stress, leading to a reduction in the transpiration process and, consequently, in plant growth (SILVA et al., 2018).

The analysis of ECw considering each SA concentration, for the variable Ci, was significant, with a better fit of the quadratic model (Figure 6B), and the maximum value was 188.87 µmol m^{-2} s^{-1}, at SA concentration of 4.5 mM L^{-1} and ECw of 2.3 dS m^{-1}. It is possible to observe a certain similarity in relation to the analysis of SA considering each ECw level (Figure 5B), where the increase in ECw is conditioning the elevation in Ci. The increment of Ci promoted by the increase in ECw is justified by possible changes in or damage to the photosynthetic apparatus, besides being an indication that there is no CO_2 flow for the synthesis of organic compounds (TAIZ et al., 2017).



Vertical bars represent the standard error. * - significant at $p \leq 0.05$ by the F test. CV = coefficient of variation.

Figure 6. Decomposition of the interaction for the variables: Transpiration (A) and intercellular CO_2 concentration (B) of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water – ECw and different concentrations of salicylic acid – SA, at 82 DAS.

Based on the analysis of variance summary (Table 4), the salinity levels of irrigation water (SL) caused significant effects on shoot fresh mass (SFM), root fresh mass (RFM) and root dry mass (RDM). Salicylic acid concentrations caused significant effects on shoot fresh mass (SFM), shoot dry mass (SDM) and Dickson quality index (DQI) of 'BRS Gigante Amarelo' passion fruit seedlings at 82 DAS.

Table 4. Summary of the analysis of variance for shoot fresh mass (SFM), shoot dry mass (SDM), root fresh mass (RFM), root dry mass (RDM) and Dickson quality index (DQI) of 'BRS Gigante Amarelo' passion fruit seedlings as a function of different salinity levels of irrigation water (SL) and concentrations of salicylic acid (SA), at 82 DAS.

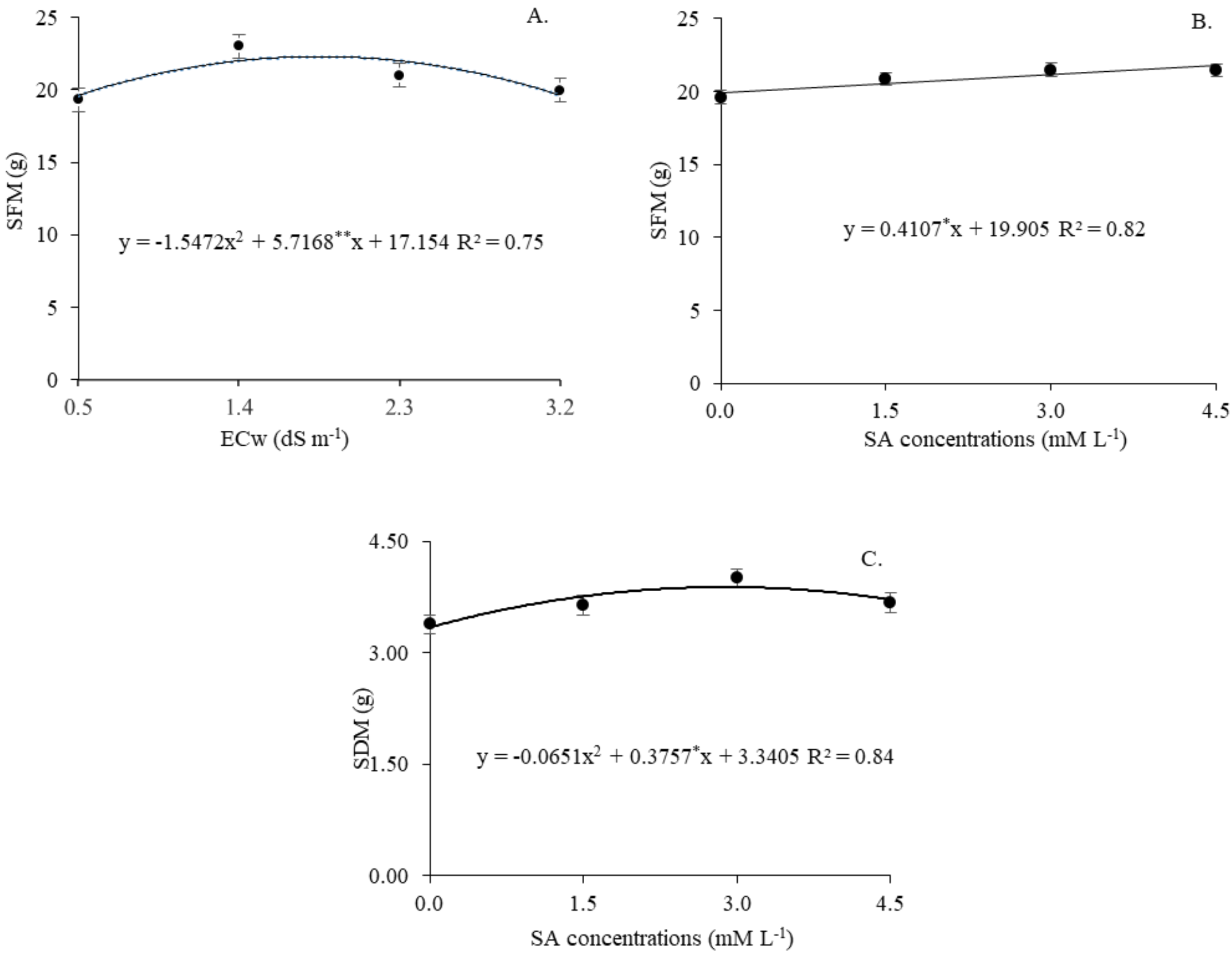
Source of Variation	Mean Square				
	SFM	SDM	RFM	RDM	DQI
Salinity Level (SL)	31.41**	0.13^{ns}	1.61*	0.03*	0.002^{ns}
Linear Reg.	0.0001^{ns}	0.32^{ns}	4.46*	0.09*	0.004^{ns}
Quadratic Reg.	67.40**	0.06^{ns}	0.31^{ns}	0.005^{ns}	0.001^{ns}
SA concentrations	9.21*	0.78*	0.23^{ns}	0.009^{ns}	0.11*
Linear Reg.	22.78*	0.92*	0.66^{ns}	0.002^{ns}	0.002^{ns}
Quadratic Reg.	4.82^{ns}	1.03*	0.004^{ns}	0.02^{ns}	0.023*
Interaction (SL x SA)	10.28^{ns}	0.52^{ns}	0.35^{ns}	0.005^{ns}	0.002^{ns}
Block	1.35^{ns}	0.17^{ns}	0.08^{ns}	0.0009^{ns}	0.001^{ns}
CV(%)	14.61	12.59	33.18	21.51	19.21

ns, **,* respectively not significant, significant at $p \leq 0.01$ and $p \leq 0.05$ by the F test. CV = coefficient of variation.

The increase in irrigation water salinity caused a significant effect on SFM at 82 DAS (Table 4), with a quadratic response according to the regression equation (Figure 7A), whose highest value (22.43 g) was obtained at the ECw level of 1.80 dS m^{-1} and the lowest value at ECw of 3.2 dS m^{-1}. This reduction in SFM may be related to the ionic imbalance caused by water salinity, altering plant growth and fresh biomass production. When plants absorb water with excess salts, mainly Na^{+} and Cl^{-}, they partially close their stomata, reducing gas exchange and transpiration, as observed in the present study (Figures 4A, 5A and 6A), in addition to possibly causing damage to the photosynthetic apparatus, which results in nutritional imbalances, decreased turgor pressure, reductions in RGR_{PH} (Figure 3A), leading to less growth of these plants, and less SFM accumulation (Figure 7A) (BONACINA et al., 2022). Although the biomass was reduced by 3.5% between the ECw levels of 0.5 dS m^{-1} and 3.2 dS m^{-1}, the reduction was small, which demonstrates tolerance of this plant material to salts.

The increase in salicylic acid concentrations significantly influenced ($p \leq 0.05$) SFM at 82 DAS (Table 4), and the regression equation (Figure 7B) showed an increasing linear effect on the order of 2.06% per unit increment in SA concentration, with an increase of 9.29% (1.83 g) in plants under the highest SA concentration compared to those that did not receive SA. This increase in fresh biomass may be related to the mediating action of SA in photosynthetic processes and nutrient absorption, which contributes to biomass production (AMANY; IBRAHIM, 2015).

The concentrations of salicylic acid promoted a significant effect ($p \leq 0.05$) on the shoot dry mass of 'BRS Gigante Amarelo' passion fruit seedlings at 82 DAS and, according to the regression equation (Figure 7C), the best fit was obtained with the quadratic model, with a maximum value of 3.88 g at the SA concentration of 2.90 mM L^{-1}. This occurred possibly because salicylic acid influences various physiological processes, besides contributing to the absorption of essential elements for plant development, which promotes greater biomass (AHMED et al., 2021).

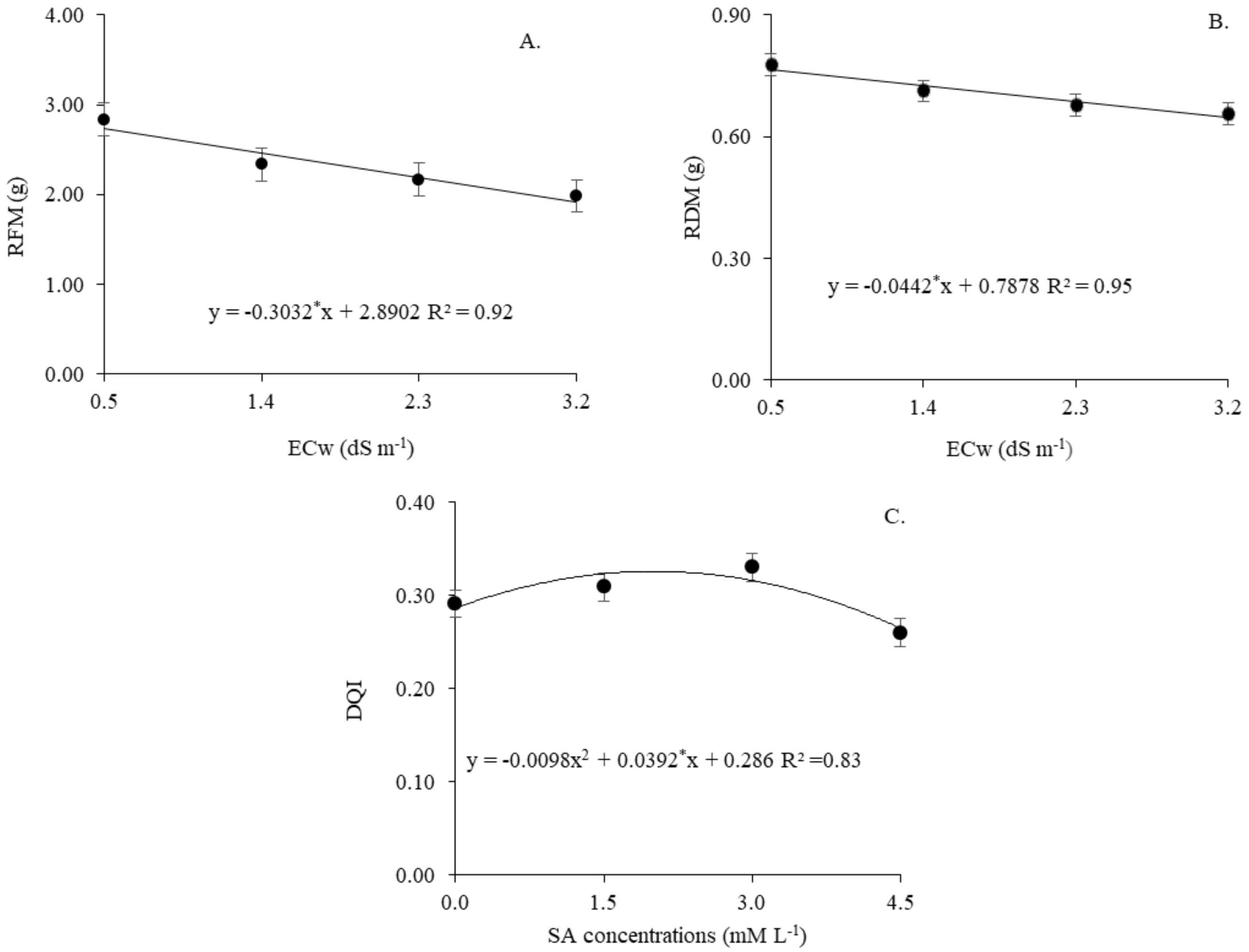


Vertical bars represent the standard error. **,*- Significant at $p \leq 0.01$ and at $p \leq 0.05$, respectively, by the F test. CV = coefficient of variation.

Figure 7. Shoot fresh mass – SFM (A and B) and shoot dry mass - SDM (C) of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water - ECw (A) and different concentrations of salicylic acid - SA (B and C), at 82 DAS.

The root fresh mass and root dry mass of passion fruit were significantly affected by salinity, with quadratic response (Figures 8A and 8B), showing linear decreases of 10.49% (RFM) and 5.61% (RDM) per unit increment in ECw and reductions of 28.33% (RFM) and 15.15% (RDM) in plants irrigated with water of 3.2 dS m^{-1} compared to those irrigated with ECw of 0.5 dS m^{-1}. The reductions in RFM and RDM with increased salinity are probably associated with the osmotic effect caused by Na^{+} and Cl^{-} ions, which at high concentrations affect water balance in the apoplastic-symplastic pathways (BONACINA et al., 2022).

There was a significant effect ($p \leq 0.05$) of salicylic acid concentrations on DQI at 82 DAS (Table 4), with a quadratic response according to the regression equation (Figure 8C), and its highest value (0.33) was obtained with the SA concentration of 2 mM L^{-1}. The index reflects the quality of seedlings and whether they will be suitable to field conditions, so its determination becomes indispensable; hence, the higher the DQI, the better the quality. Seedlings are considered of good quality when they have a value equal to or greater than 0.20 (OLIVEIRA et al., 2013).



Vertical bars represent the standard error. *- Significant at $p \leq 0.05$ by the F test. CV = coefficient of variation.

Figure 8. Root fresh mass – RFM (A), root dry mass – RDM (B) and Dickson Quality Index – DQI (C) of 'BRS Gigante Amarelo' passion fruit seedlings under increasing levels of electrical conductivity of irrigation water – ECw (A and B) and different concentrations of SA (C), at 82 DAS.

CONCLUSIONS

Electrical conductivity of irrigation water up to 3.2 dS m^{-1} does not affect the absolute growth, photosynthetic rate and Dickson quality index of 'BRS Gigante Amarelo' passion fruit seedlings;

ECw from the average value of 1.3 dS m^{-1} affects the stomatal conductance, transpiration, internal CO_2 concentration and root fresh and dry mass production of 'BRS Gigante Amarelo' passion fruit seedlings;

Foliar application of salicylic acid does not mitigate the effect of salt stress from irrigation water on the production of 'BRS Gigante Amarelo' passion fruit seedlings; however, average concentration of 3.15 mM L^{-1} promotes greater absolute and relative growth, shoot fresh and dry mass production, and quality of seedlings.

Salicylic acid concentration of 1.5 mM L^{-1}, associated with ECw of 1.0 dS m^{-1}, is recommended for the production of "BRS Gigante Amarelo" passion fruit seedlings.

REFERENCES

ABBASZADEH, B. et al. Improving water use efficiency through drought stress and using salicylic acid for proper production of *Rosmarinus officinalis* L. **Industrial Crops and Products**, 144: e111893, 2020.

AHMED, Z. F. R. et al. Melhorando a qualidade da fruta, os compostos bioativos e a vida útil da tamareira (*Phoenix dactylifera* L., cv. Barhi) usando elicitores naturais. **Horticulturae**, 7: 293, 2021.

ALVARES, C. A. et al. Koppen'sclimate classification map for Brazil. **Meteorologische Zeitschrift**, 22: 711-728, 2013.

AMANY, M. S.; IBRAHIM, H. I. M. Effect of Grain Priming with Salicylic Acid on Germination Speed, Seedling Characters, Anti-Oxidant Enzyme Activity and Forage Yield of Teosinte. **Journal Agricultural Environmental Science**, 15: 744-753, 2015.

ANDRADE, E. M. G. et al. "Peróxido de hidrogênio como atenuador do estresse salino na fisiologia e biomassa de maracujazeiro amarelo. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 26: 571-578, 2022.

AYERS, R. S.; WESTCOT, D. W. **A qualidade da água na agricultura**. Campina Grande, PB: Universidade Federal da Paraíba, 1999. 153 p.

BENINCASA, M. M. P. **Análise de crescimento de plantas: noções básicas**. Jaboticabal, SP: FUNEP, 2003. 42 p.

BONACINA, C. et al. A salinidade modula o crescimento, o metabolismo oxidativo e o perfil do óleo essencial em rizomas de *Curcuma lona* L. (*Zingiberaceae)*, **South African Journal of Botany**, 146: 1-11, 2022.

DICKSON, A., LEAF, A. L.; HOSNER, J. F. Quality appraisal of white spruce and white pine seedling stock in nurseries. **The Forest Chronicle**, 36: 10-13, 1960.

FARHANGI-ABRIZ, S.; GHASSEMI-GOLEZANI, K. How can salicylic acid and jasmonic acid mitigate salt toxicity in soybean plants. **Ecotoxicology and Environmental Safety**, 147: 1010-1016, 2018.

FALEIRO, F. G.; JUNQUEIRA, N. T. V.; COSTA, A. M. Importância socioeconômica e cultural do maracujá. In: FALEIRO, F. G.; JUNQUEIRA, N. T. V. (Eds.). **Maracujá: o produtor pergunta, a Embrapa responde**. (Coleção 500 perguntas, 500 respostas). Brasília, DF: Embrapa. 2016. v. 1, p. 15-21.

FERREIRA, D. F. SISVAR: A computer analysis system to fixed split plot type designs. **Brazilian Journal of Biometrics**, 37: 529-535, 2019.

IBGE - Instituto Brasileiro de Geografia e Estatística – IBGE. **Produção Agrícola Municipal**. 2021. Disponível em: <https://sidra.ibge.gov.br/tabela/5457#resultado%>. Acesso em: 22 dez. 2022.

JALES FILHO, R. C. et al. Ácido salicílico e prolina modulam tolerância ao estresse hídrico em variedade tradicional de feijão-caupi. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 27: 18-25, 2022.

LARCHER, W. **Ecofisiologia vegetal**. 1. ed. São Carlos, SP: RIMA, 2004. 531p.

LIMA, G. S. et al. Potassium and irrigation water salinity on the formation of sour passion fruit seedlings. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 25: 393-401, 2021.

MEDEIROS, J. F. et al. Caracterização das águas subterrâneas utilizadas para irrigação na área produtora de melão da Chapada do Apodi. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 7: 469-472, 2003.

MOURA, R. S. et al. Tolerância de espécies de maracujá ao estresse de sal. **International Journal of Current Research**, 8: 37689-37695, 2016.

NAPOLEÃO, T. A. et al. Methyl jasmonate and salicylic acid are able to modify cell wall but only salicylic acid alters biomass digestibility in the model grass *Brachypodium distachyon*. **Plant Science**, 263:46-54, 2017.

OLIVEIRA, F. T. et al. Fontes orgânicas e volume de recipiente no crescimento inicial de porta-enxertos de goiabeira. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, 8: 103, 2013.

RICHARDS, L. A. **Diagnosis and improvement of saline and alkali soils**. Washington: USDA. 1954. 160 p. (Agriculture Handbook, 60)

SILVA, A. A. R. et al. Ácido salicílico alivia o efeito do estresse salino na morfofisiologia da gravioleira. **Ciência e Agrotecnologia**, 45: e007021, 2021.

SILVA, A. A. R. et al. O ácido salicílico melhora os indicadores fisiológicos de gravioleira irrigada com águas salinas**. Revista Brasileira de Engenharia Agrícola e Ambiental**, 26: 412-419, 2022.

SILVA, E. M. et al. Growth and gas exchanges in soursop under irrigation with saline water and nitrogen sources. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 22: 776-781, 2018.

SILVA NETA, A. M. S. et al. Morphophysiology of the passion fruit 'BRS Rubi do Cerrado' irrigated with saline waters and nitrogen fertilization. **Comunicata Scientiae**, 11: 1-9, 2021.

SUN, Y. L. et al. Moderate soil salinity alleviates the impacts of drought on growth and water status of plants. **Russian Journal of Plant Physiology**, 67:153-161, 2020.

TAIZ, L. et al. **Fisiologia e desenvolvimento vegetal**. 6. ed. Porto Alegre, RS: Artmed, 2017.888 p.

TEIXEIRA, P. C. et al. **Manual de métodos de análise de solo**. 3.ed. Brasília, DF: Embrapa Solos, 2017. 574 p.

ZRIG, A. et al. Potassium and calcium improve salt tolerance of *Thymus vulgaris* by activating the antioxidant systems. **Scientia Horticulturae**, 277: e109812, 2021.