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Post-harvest fruit quality of grafted guava grown under salt stress and salicylic acid application[1]

Qualidade pós-colheita de frutos de goiabeira enxertada sob estresse salino e aplicação de ácido salicílico

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HIGHLIGHTS:
Salicylic acid at a concentration of 2.4 mM increases reducing sugars under electrical conductivity of 3.2 dS m^{-1}.
Water salinity of 3.2 dS m^{-1} and salicylic acid concentration of up to 3.6 mM promote higher contents of ascorbic acid.
The pH, total soluble solids, and ascorbic acid content obtained with water of 3.2 dS m^{-1} meet commercialization standards.

ABSTRACT: The semi-arid region of northeastern Brazil is characterized by irregular precipitation and high evapotranspiration, with a common occurrence of water sources with a high concentration of salts. In this context, this study aimed to evaluate the post-harvest fruit quality of grafted guava cv. Paluma under brackish water irrigation and foliar application of salicylic acid. The experiment was conducted under greenhouse conditions in Campina Grande, PB, Brazil, in a randomized block design, adopting a 2 × 4 factorial scheme, corresponding to two levels of electrical conductivity of irrigation water - ECw (0.6 and 3.2 dS m^{-1}) and four concentrations of salicylic acid (0, 1.2, 2.4, and 3.6 mM), with three replicates. Electrical conductivity of 0.6 dS m^{-1} and salicylic acid concentration of 2.4 mM resulted in higher levels of reducing sugars and soluble solids. Salicylic acid with concentration from 0.6 to 3.6 mM promoted increments in ascorbic acid and at concentrations of 1.9 and 1.5 mM increased the titratable acidity and total soluble sugars, respectively, in the pulp of guava irrigated with water of 3.2 dS m^{-1}. The hydrogen potential of the pulp increased with the application of salicylic acid, ranging from 1.2 to 3.6 mM, regardless of the electrical conductivity of the water.

Key words: *Psidium guajava* L., salinity, rootstock, phytohormone, chemical composition

RESUMO: A região semiárida do Nordeste brasileiro é caracterizada pela irregularidade de precipitações e elevada evapotranspiração, sendo comum a ocorrência de fontes de águas com elevadas concentração de sais. Neste contexto, este trabalho teve como objetivo avaliar a qualidade pós-colheita dos frutos de goiabeira enxertada cv. Paluma irrigadas com águas salobras e aplicação foliar de ácido salicílico. O experimento foi conduzido sob condições de casa de vegetação em Campina Grande, PB, no delineamento experimental de blocos casualizados, em esquema fatorial 2 × 4, sendo dois níveis de condutividade elétrica da água de irrigação - CEa (0,6 e 3,2 dS m^{-1}) e quatro concentrações de ácido salicílico (0; 1,2; 2,4 e 3,6 mM), com três repetições. A concentração de 1,2 mM de ácido salicílico promoveu aumento na acidez titulável, açúcares solúveis, ácido ascórbico e sólidos solúveis dos frutos de goiabeira cv. Paluma sob irrigação com água de CEa de 3,2 dS m^{-1}. A condutividade elétrica de 0,6 dS m^{-1} e concentração de ácido salicílico de 2,4 mM resultou em maiores teores de açúcares redutores e sólidos solúveis. O ácido salicílico com concentração de 0,6 até 3,6 mM promoveu incrementos de ácido ascórbico, e de 1,9 e 1,5 mM aumentou a acidez titulável e açúcares solúveis totais, respectivamente, em polpa de goiaba irrigada com água de 3,2 dS m^{-1}. O potencial de hidrogênio da polpa aumentou com a aplicação de ácido salicílico variando de 1,2 a 3,6 mM, independente da condutividade elétrica da água.

Palavras-chave: *Psidium guajava* L., salinidade, porta-enxerto, fitohormônio, composição química

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Introduction

Guava (*Psidium guajava* L.) stands out for the diversity of use of its fruits, which can be consumed fresh or processed in industries, originating several by-products such as jams, pastes, fruit in syrup, puree, the base for beverages, soft drinks, juices, and syrups (Onias et al., 2018). In 2019, Brazil produced around 584,223 tons of guava, with a large part of this production coming from the Northeast region, with Pernambuco, Bahia, and Ceará standing out as the main producing states. Paraíba state produced around 2,360 tons in a planted area of 327 hectares and with an average yield of 7,217 kg ha^{-1} (IBGE, 2022).

Despite the potential of this fruit in the Northeast region of Brazil, its production is limited by the irregularity of the rains and the high rates of evapotranspiration throughout the year, so irrigation is an indispensable practice for its cultivation in a continuous way (Machado & Serralheiro, 2017). However, most of the water from the springs of this region has high concentrations of salts and may cause morphological, structural, and metabolic alterations in plants (Lima et al., 2016) and decrease the contents of soluble solids and ascorbic acid in guava fruits (Bezerra et al., 2019).

Thus, the search for management strategies under saline conditions is essential to produce in semi-arid regions, and among those standing out are the foliar application of salicylic acid (SA) (Nazar et al., 2015) and the cultivation of grafted plants as a way to increase the salt tolerance (Zhang et al., 2018; Bezerra et al., 2019). SA is a molecule that signals stress through gene expression and promotes the expression of biosynthetic enzymes and proteins in plants under stress conditions (Wang et al., 2019). The expression of these genes promoted by the action of salicylic acid reduces the generation of reactive oxygen species (ROS) in photosynthetically active tissues (Aldesuquy et al., 2018). In this context, this study aimed to evaluate the post-harvest fruit quality of grafted guava cv. Paluma under brackish water irrigation and foliar application of salicylic acid.

Material and Methods

The experiment was carried out from April 2020 to May 2021, under greenhouse conditions, in an arch-shaped greenhouse, with a 150-micron low-density polyethylene cover and sides covered with white screen, belonging to the Academic Unit of Agricultural Engineering of the Center of Technology and Natural Resources of the Federal University of Campina Grande, PB, Brazil, located by the coordinates 07° 15’18” South latitude, 35° 52’ 28’ West longitude and an average altitude of 550 m. Data of maximum and minimum temperature and relative humidity of air collected inside the greenhouse during the experiment are presented in Figure 1.

The experimental design was randomized blocks, in a 2 × 4 factorial arrangement, whose treatments resulted from the combination of two electrical conductivities of irrigation water - ECw (0.6 and 3.2 dS m^{-1}) and four concentrations of salicylic acid (0, 1.2, 2.4, and 3.6 mM), with three replicates. The highest level of ECw was established based on studies conducted by Bezerra et al. (2019) with guava cv. Paluma, while salicylic acid (SA) concentrations used were based on a study conducted by Silva et al. (2020) with soursop (*Annona muricata* L.) crop.

Salicylic acid solutions were prepared by dissolution of the product in 30% ethyl alcohol (95.5%), as it is a substance with low solubility in water at room temperature. Wil fix® adjuvant, at a concentration of 0.5 mL L^{-1}, was used in the preparation of the solution to reduce the surface tension of the drops on the adaxial and abaxial sides of leaves. Applications of salicylic acid started 45 days after transplanting (DAT) and extended to the full flowering stage (205 DAT). The frequency of application was at an interval of 30 days and, on average, a volume of 683.33 mL of the solution per plant was applied according to treatment. The applications were performed at 5:00 p.m. and, during the application, the plant was isolated using plastic curtains to prevent the solution from drifting.

The rootstocks used in this study were seedlings of ‘Crioula’ guava, from a seedling nursery located in Sousa, PB, Brazil, while the scion was the cv. Paluma. The rootstock was propagated sexually (through seeds). Grafted seedlings were acquired 70 days after grafting and transplanted 20 days after

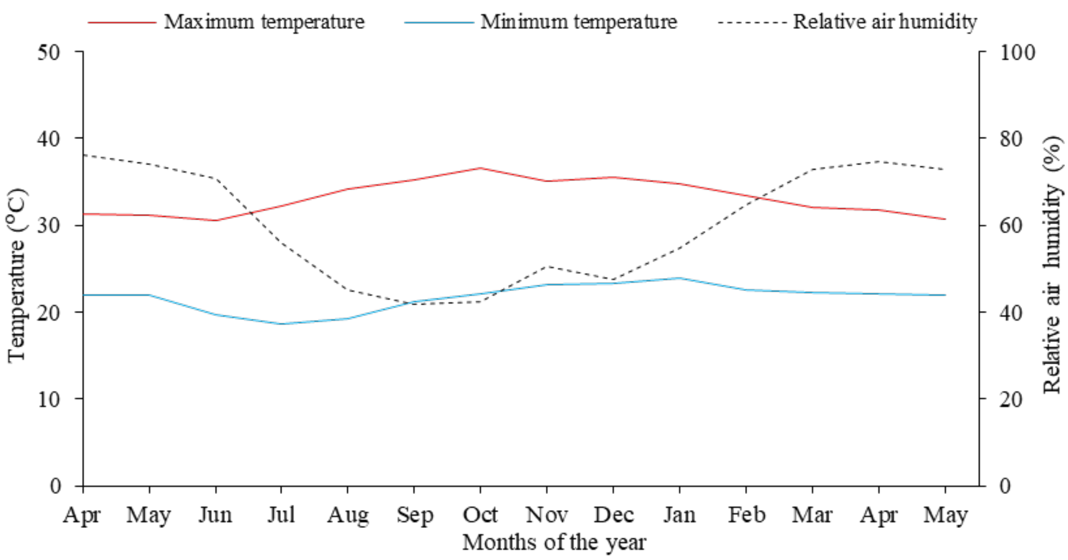


Figure 1. Maximum and minimum temperature and relative humidity of air during the experimental period

that. During the transplanting period, the seedlings had a rootstock diameter of 11.42 mm, a scion diameter of 8.92 mm, and a mean height of 35.16 cm.

Containers with capacity of 200 L adapted as drainage lysimeters were used. At the base of each lysimeter, a drain with 16 mm diameter was installed to drain the excess water and connected to a container for collecting drained water, which permitted determination of water consumption by the plants. The end of the drain inside the pot was wrapped with a nonwoven geotextile (Bidim OP 30) to prevent clogging by soil material.

The lysimeters were filled by placing a 1.0-kg layer of crushed stone number 0, followed by 250 kg of an Entisol of loamy sand texture (0-0.20 m depth), properly pounded to break up clods, from the rural area of Lagoa Seca, PB, Brazil, whose chemical and physical characteristics (Table 1) were obtained according to the methodologies recommended by Teixeira et al. (2017).

The water with the lowest electrical conductivity (0.6 dS m^{-1}) was obtained from the public supply system of Campina Grande city, PB, Brazil. Its chemical composition is presented in Table 2. Whereas the highest level of ECw (3.2 dS m^{-1}) was prepared by dissolving NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts, in the equivalent proportion of 7:2:1, respectively, in public-supply water of Campina Grande, PB, Brazil, considering the relationship between ECw and the concentration of salts, according to Eq. 1:

$$Q = 10 \cdot ECw \tag{1}$$

where:

Q - concentration of salts to be dissolved (mmol$_c$ L^{-1}); and,

ECw - electrical conductivity of water (dS m^{-1}).

Transplanting was performed into holes with dimensions 0.20 × 0.20 × 0.20 m and, before being transplanted, the seedlings were assessed for root coiling. After transplanting, the seedlings were acclimatized for 50 days and, during this period, water with electrical conductivity of 0.6 dS m^{-1} was used in irrigation.

Before transplanting the seedlings, soil moisture content was increased until reaching the maximum water retention capacity using water with ECw of 0.6 dS m^{-1}. The differentiation of water salinity levels started at 75 DAT, with irrigation performed daily at 5:00 p.m., and the volume of water to be applied in each lysimeter was determined by Eq. 2:

$$VI = \frac{(Va - Vd)}{(1 - LF)} \tag{2}$$

where:

VI - volume of water to be used in the next irrigation event (mL);

Va - volume applied in the previous irrigation event (mL);

Vd - volume drained after the previous irrigation event (mL); and,

LF - leaching fraction of 0.10 applied every 15 days.

Formative pruning was carried out when the plants reached 0.50 m height, and a cut was made in the branch of apical dominance to stimulate the production of lateral branches. With the emergence of new branches, well-distributed and balanced main branches were selected, and then these lateral branches were cut (in the lignified part) when they reached 0.40 m in length, as described by Lacerda et al. (2022). Formative pruning was performed after transplanting the seedlings into the lysimeters and started at 30 DAT.

Fertilization with nitrogen, potassium, and phosphorus was performed as recommended by Cavalcanti (2008), applying 100, 100, and 60 g per plant per year of N, P_2O_5, and K_2O, using urea (45% N), potassium chloride (60% K_2O), and monoammonium phosphate (50% P_2O_5, 11% N) as sources, respectively. Fertilization started 15 DAT and was performed in fortnightly applications. The fertilizers utilized in this study were chosen based on the acquisition cost and market availability in the region.

Fertilizations with micronutrients were also performed fortnightly by foliar applications, beginning at 30 DAT, on the adaxial and abaxial sides, with a solution at the concentration of 1.0 g L^{-1} of Dripsol Micro® (1.2% magnesium, 0.85% boron,

Table 1. Chemical and physical characteristics of the soil (0-0.20 m) used in the experiment, before the application of the treatments

Chemical characteristics							
pH H_2O 1:2.5	OM (g dm^{-3})	P (mg dm^{-3})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$Al^{3+} + H^+$
			(cmol$_c$ kg^{-1})				
6.5	8.1	79	0.24	0.51	14.90	5.40	0.90

Chemical characteristics					Physical characteristics				
EC_{se} (dS m^{-1})	CEC (cmol$_c$ kg^{-1})	ESP (%)	SB (cmol$_c$ kg^{-1})	V (%)	Particle-size fraction (g kg^{-1})			Moisture content (dag kg^{-1})	
					Sand	Silt	Clay	33.42 kPa[1]	1519.5 kPa[2]
2.15	21.95	2.32	21.05	95.89	572.7	100.7	326.6	25.91	12.96

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; ECse - Electrical conductivity of saturation extract; CEC - Cation exchange capacity; ESP - Exchangeable sodium percentage; SB - Sum of bases ($K^+ + Ca^{2+} + Mg^{2+} + Na^+$); V - Base saturation ([SB/CEC] × 100); [1,2] - Referring 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^-	SO_4^{2-}	EC (dS m^{-1})	pH	SAR (mmol L^{-1})$^{0.5}$
(mmol$_c$ L^{-1})										
1.22	2.36	0.74	0.32	1.71	0.00	2.08	Absent	0.60	7.39	0.55

EC - Electrical conductivity; SAR - Sodium adsorption ratio

3.4% iron, 4.2% zinc, 3.2% manganese, 0.5% copper, and 0.06% molybdenum).

Phytosanitary management was carried out preventively to control the possible attacks of pests: guava psyllid (*Triozoida limbata*), fruit fly (*Anastrepha* spp., *Ceratitis capitata*), bedbug (*Leptoglossus gonagra*), and Florida wax scale (*Ceroplastes floridensis*), through selective chemicals.

Harvest was carried out manually from March to May 2021. The fruits were harvested based on their color, considering the change from green to yellow color as the harvest point. Subsequently, the fruits were stored for 15 days in a freezer at -10 °C to reduce the respiratory intensity and increase their post-harvest shelf life as they are climacteric fruits.

At 390 DAT, the chemical characteristics of the fruits were determined through hydrogen potential - pH, soluble solids - SS (°Brix), titratable acidity - TA (% citric acid), contents of reducing soluble sugars - RSg, and total soluble sugars - TSSg (mg $100g^{-1}$ of pulp), ascorbic acid - AA (mg $100g^{-1}$ of pulp), flavonoids - FLA (mg $100g^{-1}$ of pulp), anthocyanins - ANT (mg $100g^{-1}$ of pulp), lipids - LIP (%), and ash - ASH (%).

The pH of the fruit pulp was determined using a digital pH meter with a glass membrane electrode and a resolution of 0.01. Soluble solids were expressed in °Brix and determined using a portable refractometer with a resolution of 0.2. Titratable acidity was measured according to the methods of the Adolfo Lutz Institute (IAL, 2008) and expressed as a percentage of citric acid. Reducing and total sugars were determined using the anthrone reaction (Hodge & Hodfreiter, 1962).

The ascorbic acid concentration was determined by titration, using 0.5 g of pulp, plus 49.5 mL of oxalic acid (0.5%) and titrated against Tillman's solution until the appearance of pink color (IAL, 2008). Flavonoid and anthocyanin concentrations were determined according to Adolf Lutz Institute (IAL, 2008). Ash content (%) was determined according to the method 018/IV of the Adolf Lutz Institute (IAL, 2008), and the results were expressed in percentage (w/w). Lipids (%) were determined using the Soxhlet extractor apparatus, following the method 033/IV of the Adolf Lutz Institute (IAL, 2008).

The data collected in this study were subjected to the normality and homogeneity test (Shapiro-Wilk test) followed by the analysis of variance. The F test was applied to the electrical conductivity levels of water ($p \le 0.05$) and for salicylic acid, when significant, linear and quadratic polynomial regression analyses were performed. When there was a significant interaction between the factors, the electrical conductivity was further analyzed considering each salicylic acid concentration, using the statistical program Sisvar version 5.7 (Ferreira, 2019). Due to the heterogeneity of LIP, verified through the tests of normality and homogeneity of variances, the data were transformed to $\sqrt{x}$ before analysis of variance.

Results and Discussion

There was a significant effect of the interaction between SL × SA for hydrogen potential, titratable acidity, and lipid contents of guava fruits (Table 3). Also, there was an isolated effect of the electrical conductivity of irrigation water and of the concentration of salicylic acid on the hydrogen potential, titratable acidity, and lipid contents in the pulp of guava fruits, cv. Paluma. The ash contents of guava pulp were not significantly influenced by salinity levels and salicylic acid concentrations.

Table 3. Summary of the F test for hydrogen potential (pH), titratable acidity (TA, % citric acid), contents of lipids (LIP, %), and ash (ASH, %) in the fruit pulp of guava, cv. Paluma, cultivated under irrigation with brackish water and foliar application of salicylic acid

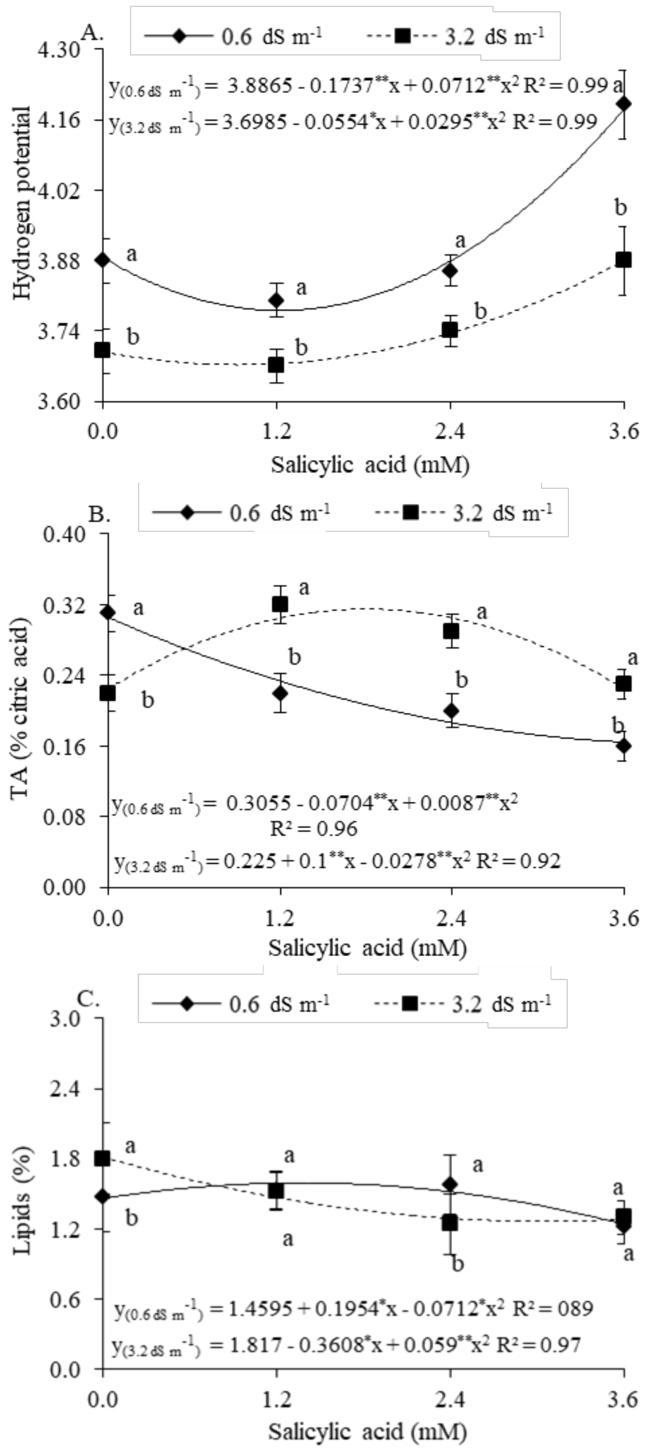
Source of variation	F test			
	pH	TA	LIP[1]	ASH
Salinity levels (ECw)	**	**	**	ns
Salicylic acid (SA)	**	**	**	ns
Interaction (ECw × SA)	**	**	**	ns
Blocks	ns	ns	ns	ns
CV (%)	1.16	6.2	10.07	4.53
Mean	3.84	0.24	1.10	87.80

ns, ** - Not significant and significant by F test at $p \le 0.01$; [1] - Data transformed to $\sqrt{x}$

Guava plants irrigated with water with an electrical conductivity of 0.6 dS m^{-1} obtained the highest hydrogen potential of pulp (4.18) when they received the application of salicylic acid at a concentration of 3.6 mM (Figure 2A). When comparing the pH of plants grown under ECw of 0.6 dS m^{-1}, there was an increase of 0.29 between those that received salicylic acid concentrations of 0 and 3.6 mM. Likewise, when the plants received the water with the highest salinity level (3.2 dS m^{-1}) and the application of 3.6 mM of salicylic acid, the highest value (3.88) for the pH of the pulp of guava was obtained (Figure 2A). In plants under irrigation with 3.2 dS m^{-1} water, the foliar application of 3.6 mM SA increased the pH of guava fruit pulp by 0.18 compared to the control treatment (0 mM). Analysis of the interaction for ECw levels at each salicylic acid concentration showed that the pH of the fruit pulp of plants irrigated with ECw of 0.6 dS m^{-1} was statistically higher than the values found in those subjected to water salinity of 3.2 dS m^{-1}.

The pH is an important component when it comes to fruit quality because low values can guarantee pulp conservation with no need for high thermal treatment, thereby preventing a loss of nutritional quality (Benevides et al., 2008). Thus, irrigation with ECw of 0.6 and 3.2 dS m^{-1} associated with foliar application of SA with a concentration of up to 3.6 mM favored this variable. In the present study, the pH of the fruit pulp remained within the appropriate standard for commercialization, as the highest value observed was 4.19, that is, above the minimum value (3.5) recommended by the Ministry of Agriculture through the Normative Instruction nº 49, of September 26, 2018 (Brasil, 2018). The data found in the present study differ from the results reported by Bezerra et al. (2019), who evaluated the post-harvest fruit quality of guava cv. Paluma as a function of water salinity (ECw: 0.3 to 3.5 dS m^{-1}) and observed no significant difference in fruit pH due to ECw and cultivation cycles.

Regarding titratable acidity (Figure 2B), plants subjected to irrigation with water of 0.6 dS m^{-1} and foliar application of 0 mM obtained the maximum value of 0.306% citric acid. At this same level of ECw, the application of 3.6 mM led to the minimum value of TA (0.165% citric acid.). When comparing plants irrigated with ECw of 0.6 dS m^{-1} and subjected to foliar



Means followed by different letters indicate significant difference by F test ($p \leq 0.05$); Vertical bar represents the standard error of the mean (n = 3)

Figure 2. Hydrogen potential (A), titratable acidity - TA (B), and lipid contents (C) of guava fruit pulp as a function of salicylic acid concentrations and electrical conductivities of water - ECw

application of salicylic acid at the highest concentration (3.6 mM) with those under the control treatment (0 mM), there was a quantitative reduction of 0.141% in TA. Plants irrigated with water of 3.2 dS m^{-1} reached the highest TA value (0.315% citric acid) under SA application of 1.9 mM. Analysis of the interaction for electrical conductivity levels at each salicylic acid concentration (Figure 2B) showed that the TA of plants irrigated with ECw of 0.6 dS m^{-1} was statistically higher than that of plants cultivated under the highest salinity level (3.2 dS m^{-1}) only in the control treatment. Plants irrigated with ECw of 3.2 dS m^{-1} obtained statistically higher TA compared to those cultivated under the lowest level of water salinity (0.6 dS m^{-1}) and foliar application of 1.2, 2.4, and 3.6 mM of SA.

The increase in titratable acidity in the pulp of guava fruits may be associated with the reduction of water availability to the plant due to the osmotic effect caused by excess salts in the soil solution (Ó et al., 2021). It is important to highlight that the foliar application of SA up to a concentration of 1.9 mM in plants subjected to an ECw of 3.2 dS m^{-1} contributed to increasing the titratable acidity in the guava pulp. The increase in titratable acidity is a well-appreciated characteristic when it comes to the use of guava fruits for industry, as it reduces the need for using acidifiers, thus improving nutritional and organoleptic quality, being considered an important attribute for juice production and also for the consumption of fresh fruits (Brasil et al., 2016).

In the present study, the TA of guava pulp does not meet standards of identity and quality for juice, since the highest value obtained was 0.315% citric acid in plants grown under ECw of 3.2 dS m^{-1}, that is, lower than the value (0.4% citric acid) established by the Ministry of Agriculture through Normative Instruction No. 49, of September 26, 2018 (Brasil, 2018).

Similar results were reported by Lacerda et al. (2021) while evaluating the fruit quality of West Indian cherry (*Malpighia emarginata* Sesse & Moc. ex DC) cv. Flor Branca, subjected to irrigation with different levels of water salinity (ECw: 0.3 to 4.3 dS m^{-1}); these authors reported a linear increase in total titratable acidity as the ECw levels increased, with an increment of 26.05% per unit increase in ECw.

For the lipid contents in the pulp of guava fruits (Figure 2C), in plants subjected to irrigation with water of 0.6 dS m^{-1} the maximum estimated value of 1.594% was obtained under foliar application of 1.4 mM, decreasing from this concentration and reaching the minimum value of 1.240% in plants that received 3.6 mM. Compared to plants subjected to water salinity of 3.2 dS m^{-1}, the control treatment (0 mM SA) resulted in a maximum value of 1.817%. Under ECw of 3.2 dS m^{-1}, plants subjected to the application of 3.6 mM decreased their quantitative lipid levels by 0.534% in comparison to those that received 0 mM of SA. Analysis of the interaction between salinity level and salicylic acid concentration (Figure 2C) showed that the lipid contents of plants subjected to ECw of 0.6 dS m^{-1} differed significantly from that of plants irrigated with water of 3.2 dS m^{-1} when they received the foliar application of 0 and 2.4 mM of SA. There were no significant differences between plants grown under ECw of 0.6 and 3.6 dS m^{-1} and foliar application of 1.2 and 3.6 mM of SA. The reduction in lipid contents in fruits is probably related to the decrease in membrane susceptibility to oxidative damage, helping to protect its integrity. In addition, changes in lipid synthesis can directly affect the properties of proteins and the activity of signaling molecules, adjusting the fluidity and permeability of membranes by activating signal transduction pathways (Guo et al., 2019).

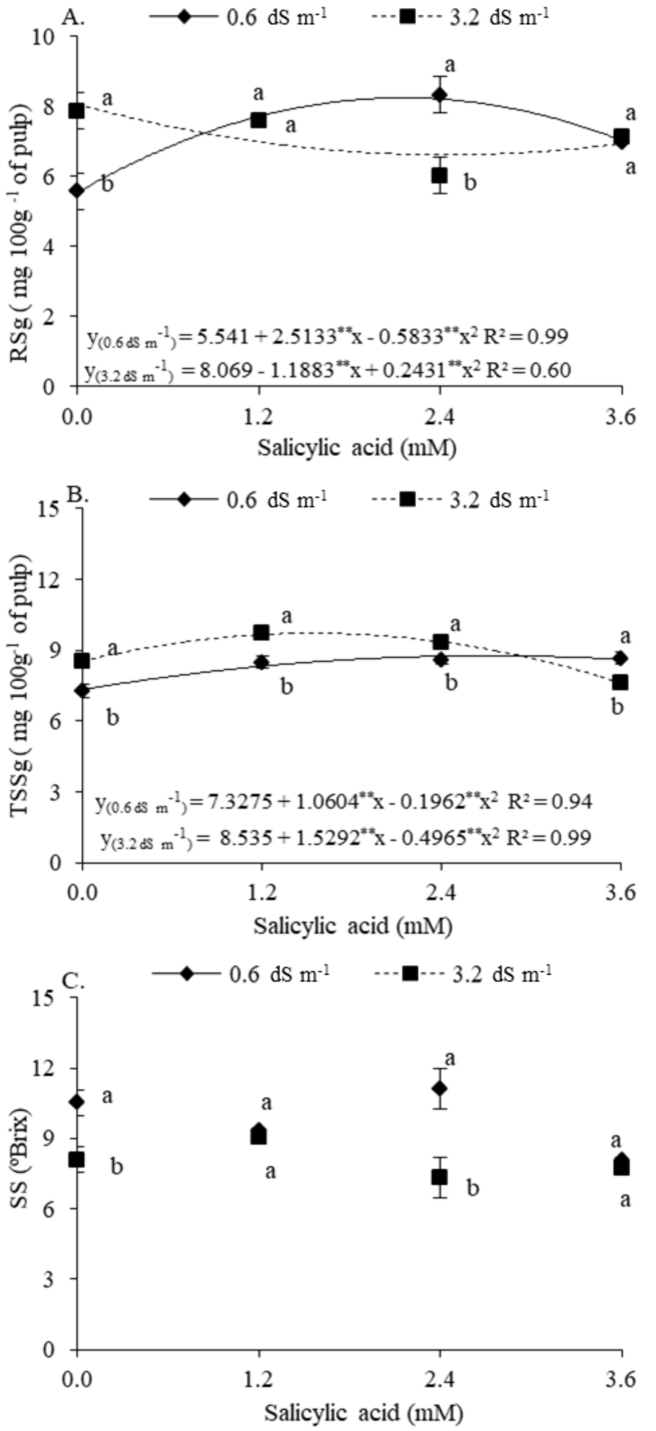
There was a significant effect of the interaction between the factors (ECw × SA) on the contents of reducing sugars

(RSg), total soluble sugars (TSSg), soluble solids (SS), ascorbic acid (AA), flavonoids (FLA), and anthocyanins (ANT) of guava fruits (Table 4). Also, there was an isolated effect of the electrical conductivity levels of the water and concentrations of salicylic acid on all variables evaluated.

For the contents of reducing sugars (Figure 3A) in the pulp of guava fruits, in plants cultivated with the lowest level of electrical conductivity (0.6 dS m^{-1}), the highest value found was 8.247 mg $100g^{-1}$ of pulp under foliar application of 2.2 mM of salicylic acid. For plants subjected to irrigation with water of 3.2 dS m^{-1} and foliar application of 0 mM, a maximum value of 8.069 mg $100g^{-1}$ of RSg in the pulp was observed. Regarding the effect of the interaction between ECw levels and SA (Figure 3A), the irrigation water of 0.6 dS m^{-1} promoted statistically higher RSg contents compared to the values observed in plants irrigated with water of 3.2 dS m^{-1} and 2.4 mM of salicylic acid. On the other hand, irrigation with water of electrical conductivity of 3.2 dS m^{-1} stood out with higher RSg contents compared to those cultivated under ECw of 0.6 dS m^{-1} and application of 0 mM. For the other salicylic acid concentrations, there were no significant differences between the ECw levels for RSg.

The contents of reducing sugars in plants grown under salt stress are compatible with soluble solids and are possibly associated with a reduction in the synthesis of hexose sugars, mainly glucose and fructose (Li et al., 2018). The increase of reducing sugars in the cell is capable of stabilizing macromolecular structures, which contribute to restoring the integrity of the plasma membrane (Orcutt & Nilsen, 2000). The results found in this study corroborate those reported by Lacerda et al. (2021), who observed a reduction in sugar content in West Indian cherry fruits with increasing water salinity.

Regarding the contents of total soluble sugars (Figure 3B) in the pulp of guava fruits, in plants irrigated using water with electrical conductivity of 0.6 dS m^{-1} the maximum value of 8.760 mg $100g^{-1}$ of pulp was achieved under foliar application of 2.7 mM of SA. Plants grown under irrigation with water of 3.2 dS m^{-1} obtained the highest content of soluble sugars (9.712 mg $100g^{-1}$ of pulp) when they received a salicylic acid concentration of 1.5 mM, while the minimum estimated value for total soluble sugars (7.605 mg $100g^{-1}$ of pulp) was observed in plants under foliar application of 3.6 mM of SA. In the analysis of the interaction for ECw levels at each concentration of salicylic acid (Figure 3B), it can be noted that water salinity of 3.2 dS m^{-1} promoted the highest total soluble sugar contents in the pulp of guava fruits when SA concentrations of 0, 1.2 and 2.4 mM were used. However, when using the highest concentration of SA, the higher total soluble sugar contents were verified in plants subjected to the lowest level of ECw (0.6 dS m^{-1}).



Means followed by different letters indicate significant difference by F test ($p \leq 0.05$). The vertical bar represents the standard error of the mean (n = 3)

Figure 3. Reducing sugars - RSg (A), total soluble sugars - TSSg (B), and soluble solids - SS (C) in the pulp of guava fruits as a function of salicylic acid concentration and electrical conductivities of water - ECw

Table 4. Summary of the F test for the contents of reducing sugars (RSg, mg $100g^{-1}$ of pulp), total soluble sugars (TSSg, mg $100g^{-1}$ of pulp), soluble solids (SS, °Brix), ascorbic acid (AA, mg $100g^{-1}$ of pulp), flavonoids (FLA, mg $100g^{-1}$ of pulp), and anthocyanins (ANT, mg $100g^{-1}$ of pulp) in the pulp of fruits of guava cv. Paluma cultivated under irrigation with brackish water and application of salicylic acid

Source of variation	F test					
	RSg	TSSg	SS	AA	FLA	ANT
Salinity levels (ECw)	**	**	**	**	**	**
Salicylic acid (SA)	**	**	**	**	**	**
Interaction (ECw × SA)	**	**	**	**	**	**
Blocks	ns	ns	ns	ns	ns	ns
CV (%)	0.88	1.38	0.71	5.02	0.69	4.15
Mean	7.14	8.51	8.91	106.26	9.10	1.01

ns, ** - Not significant and significant at $p \leq 0.01$

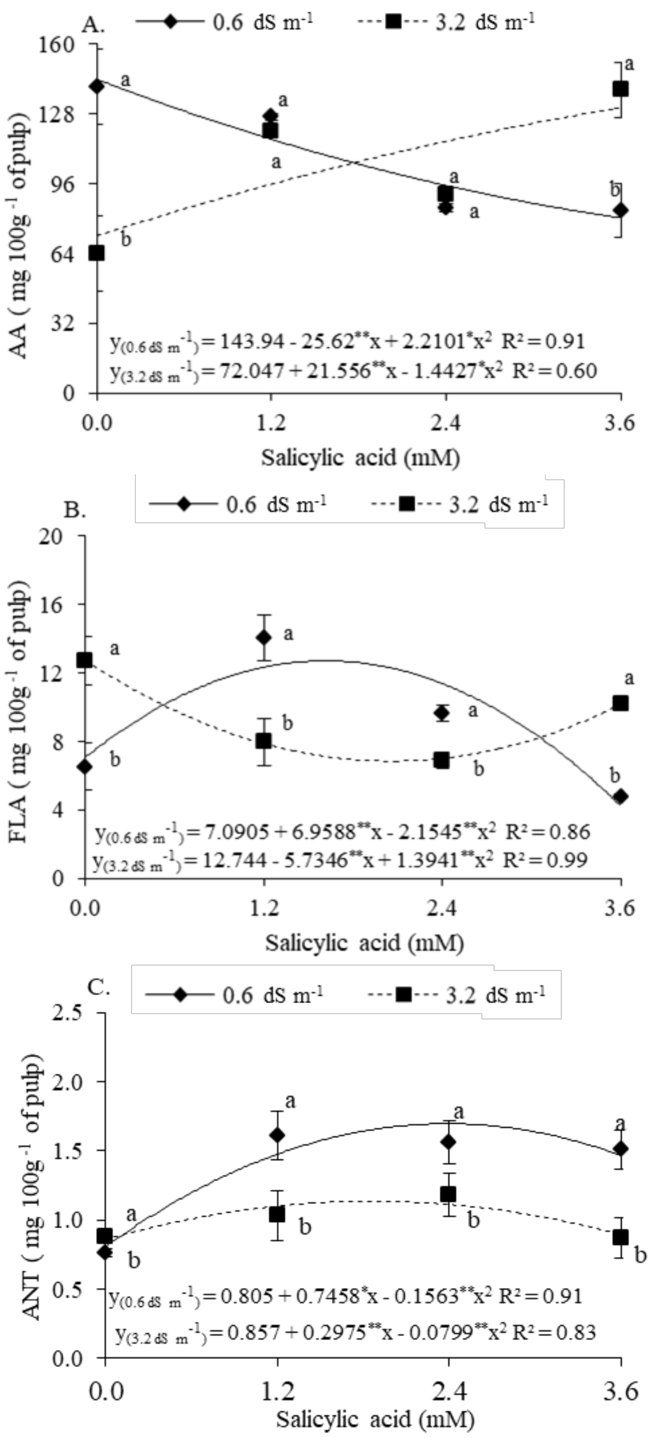
The increase in the contents of total soluble sugars observed mainly in plants grown under the highest level of ECw may be associated with the stress signaling capacity promoted by salicylic acid; consequently, the plant adjusted itself osmotically as a defense mechanism. Sugars can act as osmotic protectants during cell dehydration caused by abiotic stresses, such as water restriction caused by the osmotic effect, as a consequence of excess salts in water and/or soil (Matos Filho & Carvalho, 2020).

The data obtained for soluble solids contents (Figure 3C) were not satisfactorily described by the models tested from a prognostic point of view, as R^2 values were approximately 30-44%: $y_{(0.6\ dS\ m^{-1})} = 10.143 + 0.7025^{**}x - 0.3229^{**}x^2$, $R^2 = 0.44$; $y_{(3.2\ dS\ m^{-1})} = 8.3365 + 0.0971^{**}x - 0.092^{**}x^2$, $R^2 = 0.30$. Analysis of the interaction for electrical conductivity of water at each concentration of salicylic acid (Figure 3C) showed that plants under irrigation with ECw of 0.6 dS m^{-1} obtained higher soluble solids contents than those subjected to the highest salinity level (3.2 dS m^{-1}) with foliar application of 0 and 2.4 mM of SA. SA application of 1.2 and 3.6 mM did not significantly influence the SS contents of plants irrigated with ECw of 0.6 and 3.2 dS m^{-1}.

As verified for pH, SS contents are within the commercial standards, since the minimum acceptable content according to the Ministry of Agriculture through Normative Instruction No. 49 of September 26, 2018, is 7.0 °Brix, and the minimum and maximum values found in this study were 7.49 and 10.14 °Brix, respectively. Thus, the guava pulp obtained in the present study under ECw of 0.6 and 3.2 dS m^{-1} meets the standards of identity and quality, as established by Brasil (2018), given that the values obtained ranged from 10.14 to 8.48 °Brix (ECw = 0.6 dS m^{-1}) and from 8.33 to 7.49 °Brix (ECw = 3.2 dS m^{-1}).

The reduction of soluble solids with an increase in water salinity in the pulp of guava fruits may be associated with the increase in Na^+ and Cl^- concentrations in leaves, which might have led to changes in the biochemical and physiological processes of plants and may have resulted in changes in photosynthetic activities and consequently in the translocation of assimilates (Sá et al., 2019). Linear reduction of SS with the increase of water salinity was also observed by Lacerda et al. (2021) in pulp of West Indian cherry cv. Flor Branca subjected to irrigation with different levels of water salinity (ECw: 0.3 to 4.3 dS m^{-1}).

The ascorbic acid contents of guava fruits (Figure 4A) were significantly reduced with increased SA concentrations, when the plants were irrigated with water of low salinity level (0.6 dS m^{-1}), with the highest value (143.94 mg 100g^{-1} pulp) obtained at the SA concentration of 0 mM and minimum value (80.351 mg 100g^{-1} pulp) observed under SA concentration of 3.6 mM. On the contrary, for plants grown under water salinity of 3.2 dS m^{-1}, the maximum value (130.951 mg 100g^{-1} of pulp) was obtained under the application of 3.6 mM and the minimum value was 72.047 mg 100g^{-1} of pulp in plants that did not receive salicylic acid (0 mM). When comparing the ascorbic acid contents of plants subjected to foliar application of 3.6 mM to those of plants cultivated under 0 mM of SA, there was an increase of 58.90 mg 100g^{-1} of pulp.



Means followed by different letters indicate significant difference by F test (p ≤ 0.05). Vertical bar represents the standard error of the mean (n = 3)

Figure 4. Contents of ascorbic acid - AA (A), flavonoids - FLA (B) and anthocyanins - ANT (C) in the pulp of guava fruit, as a function of salicylic acid concentration and electrical conductivities of irrigation water - ECw

Analysis of the interaction (Figure 4A) showed that plants under the lowest level of ECw (0.6 dS m^{-1}) had higher AA contents than those that were subjected to water salinity of 3.2 dS m^{-1} in the absence of foliar application of SA (0 mM). On the other hand, for SA concentration of 3.6 mM plants cultivated with ECw of 3.2 dS m^{-1} stood out with higher AA compared to those that were under irrigation with water of 0.6 dS m^{-1}.

A decrease in AA with increasing salinity is usually associated with a reduction in the contents of soluble hexose sugars, originally D-glucose or D-galactose, from which the fruits synthesize ascorbic acid (Dias et al., 2011) and may result from changes in photosynthetic activities and the translocation of photoassimilates. However, in the present study, the fruits of plants irrigated with water of 3.2 dS m^{-1} and under SA concentration of up to 3.6 mM showed an increase in ascorbic acid content. This increase may be associated with its action under abiotic stress conditions, as it is a non-antioxidant compound that acts to protect cells against oxidative stress (Sharma et al., 2019).

It is important to highlight that the ascorbic acid contents found in this study are higher than the quality standards recommended by Normative Instruction No. 49, which considers 24 mg $100g^{-1}$ of the pulp as the minimum desired value (Brasil, 2018). Bezerra et al. (2019), when evaluating the post-harvest quality of 'Paluma' guava irrigated with water of increasing salinity (ECw: 0.3 to 3.5 dS m^{-1}), found ascorbic acid contents lower than those obtained in the present study, being 19.63 and 28.52 mg $100g^{-1}$ of pulp under ECw of 0.3 and 3.5 dS m^{-1}, respectively.

Regarding flavonoid content (Figure 4B), it was observed that the SA concentration of 1.6 mM resulted in the highest value (12.709 mg $100g^{-1}$ of pulp) when plants were subjected to irrigation with ECw of 0.6 dS m^{-1}. Plants irrigated with water of 3.2 dS m^{-1} showed a maximum value (12.744 mg $100g^{-1}$ of pulp) in the absence of foliar application of SA (0 mM). Regarding the effects of ECw levels at each concentration of salicylic acid (Figure 4B), plants irrigated using water with electrical conductivity of 0.6 dS m^{-1} had higher FLA contents compared to those cultivated under the highest salinity level (3.2 dS m^{-1}) for SA concentrations of 1.2 and 2.4 mM. Plants subjected to ECw of 3.2 dS m^{-1} obtained statistically higher FLA contents compared to the values of those irrigated with the lowest salinity level at SA concentrations of 0 and 3.6 mM.

The observed increase of flavonoids in fruits of plants cultivated under low salinity of the water that occurred at SA concentrations from 0 to 1.6 mM is considered relevant, as it is a bioactive compound that performs several functions and is important for human health, being part of several functional compounds (Perez-Vizcaino & Fraga, 2018). The increase in irrigation water salinity also resulted in a decrease in flavonoid contents in West Indian cherry fruits, as verified in a study carried out by Lacerda et al. (2021).

For the anthocyanin content of guava fruits (Figure 4C), the highest value (1.69 mg $100g^{-1}$ pulp) was found in plants irrigated with ECw of 0.6 dS m^{-1} and SA concentration of 2.4 mM. Plants subjected to irrigation with water of 3.2 dS m^{-1} obtained the highest value (1.134 mg $100g^{-1}$ of pulp) at SA concentration of 1.9 mM. Analysis of the interaction for ECw levels at each SA concentration (Figure 4C) showed that the ANT contents of plants irrigated with water of 0.6 dS m^{-1} were significantly higher than the values of those cultivated under water salinity of 3.2 dS m^{-1}, regardless of the SA concentration applied. Lacerda et al. (2021), in research evaluating the quality of the West Indian cherry cv. Flor Branca, subjected to irrigation with different levels of saline water (ECw from 0.3 to 4.3 dS m^{-1}), verified that the increase in the electrical conductivity of the water reduced the anthocyanin contents. However, the values obtained, 5.197 and 1.147 mg $100g^{-1}$ of pulp under ECw of 0.3 and 4.3 dS m^{-1}, respectively, were higher than those found in the present study.

Changes in the post-harvest quality of fruits in plants grown under salt stress conditions occur due to the action of the osmotic effect in the soil solution, reducing the flow of free energy of water and inhibiting the absorption of water and nutrients by plants, as well as photosynthetic capacity (Lima et al., 2020). The results found in the present study differ from those reported by Lima et al. (2020), who evaluated the West Indian cherry crop under salt stress conditions with levels of 0.8 and 3.8 dS m^{-1} and found that the highest anthocyanin content in fruit pulp was found at the highest level of water salinity.

Conclusions

1. Irrigation with 0.6 dS m^{-1} water and 2.4 mM salicylic acid concentration results in higher levels of reducing sugars and soluble solids in guava pulp.

2. Foliar application of salicylic acid concentrations ranging from 0 to 3.6 mM promotes increases in ascorbic acid and, at concentrations of 1.9 and 1.5 mM, increases titratable acidity and total soluble sugars, respectively, in the pulp of guava cv. Paluma irrigated with 3.2 dS m^{-1} water.

3. The hydrogen potential of guava pulp increases with the application of salicylic acid with concentrations ranging from 1.2 to 3.6 mM, regardless of the electrical conductivity of the irrigation water.

4. The guava pulp produced under an electrical conductivity of 3.2 dS m^{-1} meets the market requirements in terms of ascorbic acid content, hydrogen potential, and soluble solids.

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