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Salicylic acid improves physiological indicators of soursop irrigated with saline water[1]

O ácido salicílico melhora os indicadores fisiológicos de gravioleira irrigada com águas salinas

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HIGHLIGHTS:

Low concentrations of salicylic acid promote synthesis of photosynthetic pigments in soursop.
Salicylic acid concentrations above 1.4 mM intensify the deleterious effects of salinity on chlorophyll synthesis.
Irrigation with water of electrical conductivity above 1.8 dS m^{-1} negatively affects chlorophyll a fluorescence.

ABSTRACT: Plants grown under salinity are subject to osmotic and ionic stresses that cause several physiological changes, so searching for strategies that minimize the deleterious effects is essential for the development of irrigated agriculture. In this context, the objective was to evaluate the effects of foliar applications of salicylic acid on the mitigation of the effects of salt stress on photosynthetic pigments and chlorophyll a fluorescence of soursop cv. Morada Nova. The study was conducted in a greenhouse, in a randomized block design and 5 × 4 factorial arrangement, with five values of electrical conductivity of irrigation water - ECw (0.8 - control, 1.6, 2.4, 3.2 and 4.0 dS m^{-1}) and four concentrations of salicylic acid - SA (0, 1.2, 2.4 and 3.6 mM), with three replicates. Foliar application of salicylic acid at a concentration of 1.4 mM mitigated the effects of salt stress on chlorophyll a, chlorophyll b, chlorophyll total, and carotenoids of soursop when irrigated with water of up to 1.5 dS m^{-1}. Salicylic acid at concentrations above 1.4 mM combined with irrigation with saline water intensified the deleterious effects on photosynthetic pigments. Chlorophyll a fluorescence was not influenced by salicylic acid sprays up to the concentration of 3.6 mM.

Key words: *Annona muricata* L., salinity, physiology, acclimatization

RESUMO: As plantas cultivadas sob estresse salino estão sujeitas aos estresses osmóticos e iônicos que ocasionam várias alterações fisiológicas, desta forma, a busca por estratégias que minimizem os efeitos deletérios é imprescindível para o desenvolvimento da agricultura irrigada. Neste contexto, objetivou-se, avaliar os efeitos de aplicações foliares com ácido salicílico na mitigação dos efeitos do estresse salino nos pigmentos fotossintéticos e na fluorescência da clorofila a da gravioleira cv. Morada Nova. O estudo foi conduzido em casa de vegetação, no delineamento de blocos casualizados e arranjo fatorial 5 × 4, com cinco valores de condutividade elétrica da água de irrigação - CEa (0,8 - controle; 1,6; 2,4; 3,2 e 4,0 dS m^{-1}) e quatro concentrações de ácido salicílico - AS (0; 1,2; 2,4 e 3,6 mM), com três repetições. A aplicação foliar do ácido salicílico na concentração de 1,4 mM amenizou os efeitos do estresse salino sobre a clorofila a, clorofila b, clorofila total e carotenoides da gravioleira quando irrigadas com água de até 1,5 dS m^{-1}. O ácido salicílico em concentrações acima de 1,4 mM aliado a irrigação com água salina intensificou os efeitos deletérios sobre os pigmentos fotossintéticos. A fluorescência da clorofila a não foi influenciada pelas pulverizações de ácido salicílico até a concentração de 3,6 mM.

Palavras-chave: *Annona muricata* L., salinidade, fisiologia, aclimatação

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Introduction

With the increase in the world population, food production needs to be increasingly efficient; however, crop yield has not increased along with food demand. In certain situations, low yield is due to abiotic stresses, including salt stress, one of the most threatening to the development of irrigated agriculture, since it inhibits the growth and development of crops, especially in semiarid regions (Andrade et al., 2019).

Soursop (*Annona muricata* L.) is a fruit crop of tropical climate, which finds in the Northeast region of Brazil ideal edaphoclimatic conditions for its development (Lemos, 2014). There is no consensus in the literature on the threshold salinity of soursop. However, recent studies have shown that irrigation with saline water with electrical conductivity above 1.6 dS m^{-1} has negatively affected soursop growth and physiology (Silva et al., 2020).

Thus, strategies that enable the use of saline water in agriculture are extremely important. Among these strategies, one that stands out is the use of eliciting substances, such as salicylic acid (SA), which acts to improve the efficiency of metabolic processes, resulting in acclimatization to abiotic stresses, such as salt stress (Silva et al., 2019).

The beneficial effect of foliar application of salicylic acid is related to the regulation of stomatal conductance (Khan et al., 2019), absorption of ions (Lotfi et al., 2020), reduction of oxidative damage (Souana et al., 2020), better photosynthetic activity (Batista et al., 2019), and improvement in nutrient absorption (Mallahi et al., 2018). However, studies involving the use of salicylic acid in Annonaceae species are incipient. In this context, this study aimed to evaluate the effects of foliar applications with salicylic acid on the mitigation of the effects of salt stress on photosynthetic pigments and chlorophyll a fluorescence of soursop cv. Morada Nova.

Material and Methods

The experiment was carried out during the period from June 2019 to October 2020, in a protected environment (greenhouse) belonging to the Academic Unit of Agricultural Engineering - UAEA of the Federal University of Campina Grande - UFCG, located in Campina Grande, Paraíba, Brazil, at the geographical coordinates 7° 15' 18" South latitude, 35° 52' 28" West longitude and an average altitude of 550 m. The data of temperature (maximum and minimum) and average relative humidity of air observed during the experimental period at the experimental site are shown in Figure 1.

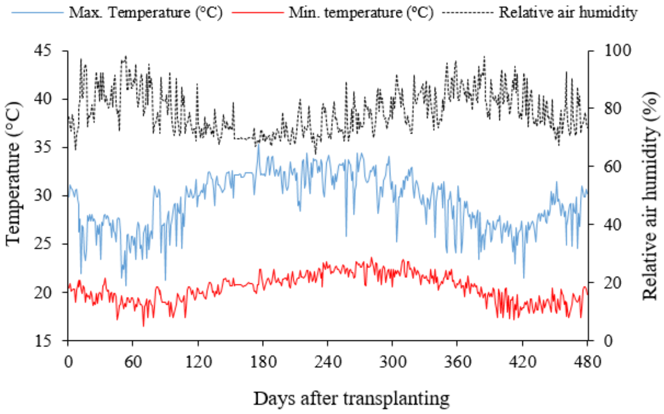


Figure 1. Air temperature (maximum and minimum) and average relative air humidity inside the greenhouse during the experimental period

The treatments consisted of five values of electrical conductivity of irrigation water - ECw (0.8, 1.6, 2.4, 3.2 and 4.0 dS m^{-1}) and four concentrations of salicylic acid - SA (0, 1.2, 2.4 and 3.6 mM), in a 5 × 4 factorial arrangement, distributed in randomized blocks, with three replicates, each with one plant, totaling 60 experimental units.

Salicylic acid concentrations were established according to a study conducted by Abbaszadeh et al. (2020) and water electrical conductivity values were based on the results of Veloso et al. (2022).

The soursop cultivar Morada Nova was chosen because it is the most appreciated by producers, planted in most commercial orchards in Brazil, besides having larger fruits, which can weigh up to 15 kg, and providing higher production compared to other cultivars (São José et al., 2014). The seedlings were propagated sexually and the formation period was 330 days. At the time of transplanting, the plants had average height of 0.5 m and an average stem diameter of 7.0 mm. After this period, transplanting was performed to plastic pots.

The experiment was conducted using plastic pots adapted as drainage lysimeters, with capacity of 120 L, filled with a 1.0 kg layer of crushed stone followed by 160 kg of soil classified as Entisol, collected at 0-30 cm depth, from the municipality of Lagoa Seca, Paraíba, Brazil, whose physical-chemical characteristics (Table 1) were determined according to methodologies described by Teixeira et al. (2017).

The irrigation waters with different values of electrical conductivity were prepared by adding NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts, in the equivalent proportion of 7:2:1, respectively, in local supply water (ECw = 0.38 dS m^{-1}). This

Table 1. Chemical and physical attributes of the soil (0-0.30 m layer), used in the experiment, before the application of the treatments

Chemical characteristics									
pH (H_2O) 1:2.5	OM (dag kg^{-1})	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$Al^{3+} + H^+$	ESP (%)	ECse (dS m^{-1})
			($cmol_c$ kg^{-1})						
5.90	1.36	6.80	0.22	0.16	2.60	3.66	1.93	1.87	1.0
Physical-hydraulic characteristics									
Particle-size fraction (g kg^{-1})			Textural class	Moisture (kPa)		AW (dag kg^{-1})	Total porosity (%)	BD	PD
Sand	Silt	Clay		33.42*	1519.5**				
				(dag kg^{-1})				(kg dm^{-3})	
732.9	142.1	125.0	SL	11.98	4.32	7.66	47.74	1.39	2.66

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+} and H^+ - Extracted with 0.5 M CaOAc at pH 7.0; ESP - Exchangeable sodium percentage; ECse - Electrical conductivity of saturation extract; SL - Sandy loam; AW - Available water; BD - Bulk density; PD - Particle density; * Field capacity; ** Permanent wilting point proportion is commonly found in sources of water used for irrigation in small properties in the Northeast. The irrigation waters were prepared considering the relationship between ECw and salt concentration (Richards, 1954), according to Eq. 1:

$$Q = 10\ \text{ECw} \quad (1)$$

where:

Q - quantity of salts to be added ($mmol_c\ L^{-1}$); and,
ECw - electrical conductivity of water ($dS\ m^{-1}$).

At 75 days after transplanting (DAT), irrigation with saline water began, adopting an interval of three days, applying the water in each lysimeter, according to treatment to maintain soil moisture close to field capacity. The volume to be applied was determined according to the water requirement of the plants, estimated by water balance, as shown in Eq. 2:

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

where:

VI - volume of water to be used in the irrigation event (mL);
Va - volume applied in the previous irrigation event (mL);
Vd - volume drained (mL); and,
LF - leaching fraction of 0.15, applied every 30 days to avoid excessive accumulation of salts.

Salicylic acid concentrations were obtained by dissolving the product in ethyl alcohol (30%) as it is a substance of low solubility in water at room temperature. To reduce the surface tension of the drops on the leaf surface, the adjuvant Wil fix® at the concentration of 0.5 mL L^{-1} of the solution was used in the preparation of the solution.

Foliar applications began at 60 DAT, on the abaxial and adaxial sides of the leaves. Subsequent applications were performed at 30-day intervals using a backpack sprayer between 17:00 and 17:45 hours. The sprayer used is the Jacto XP® model from Jacto, with a capacity of 12 L, working pressure (maximum) of 88 psi (6 bar) and JD 12P nozzle, and the average volume applied per plant was 400 mL.

Fertilization with nitrogen, phosphorus, and potassium was based on the methodology proposed by Cavalcante et al. (2008) for soursop crop, applying 100 g of N, 60 g of P_2O_5, and 40 g of K_2O per plant per year, divided into 24 portions with 15-day intervals. Urea, monoammonium phosphate and potassium chloride were used as sources of nitrogen, phosphorus and potassium, respectively.

A Dripsol® micro solution was applied fortnightly to meet the micronutrient requirements at the concentration of 1.0 g L^{-1}, with the following composition: Mg (1.1%), Zn (4.2%), B (0.85%), Fe (3.4%), Mn (3.2%), Cu (0.5%), and Mo (0.05%), on the adaxial and abaxial sides of the leaves, using a backpack sprayer. During the experiment, tillage practices recommended for the crop such as formative and cleaning pruning, weeding, soil scarification and phytosanitary control were carried out. The crop formative pruning was performed as described by Silva et al. (2020).

At 480 DAT, when the plants had only been subjected to a formatiove pruning, the following photosynthetic pigments were evaluated: chlorophyll a (Chl a), chlorophyll b (Chl b), chlorophyll total (Chl t) and carotenoids (Car), as well as chlorophyll fluorescence: initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv = Fm - Fo) and quantum efficiency of photosystem II (Fv/Fm).

The concentrations of photosynthetic pigments (chlorophyll a, chlorophyll b, chlorophyll total, and carotenoids) were quantified according to Arnon (1949), with plant extracts from samples of discs of the blade of the third mature leaf from the apex. In each sample, 6.0 mL of 80% acetone (A.R.) were used. In these extracts, the chlorophyll and carotenoid concentrations were determined in the solutions using a spectrophotometer at absorbance wavelength (ABS) (470, 647, and 663 nm), through Eqs. 3, 4, 5 and 6:

$$\text{Chl a} = (12.25 \cdot \text{ABS663}) - (2.79 \cdot \text{ABS647}) \quad (3)$$

$$\text{Chl b} = (21.5 \cdot \text{ABS647}) - (5.10 \cdot \text{ABS663}) \quad (4)$$

$$\text{Chl t} = (7.15 \cdot \text{ABS663}) + (18.71 \cdot \text{ABS647}) \quad (5)$$

$$\text{Car} = \frac{\left[(1000 \cdot \text{ABS470}) - (1.82 \cdot \text{Chl a}) - (85.02 \cdot \text{Chl b})\right]}{198} \quad (6)$$

The values obtained for chlorophyll a, chlorophyll b, chlorophyll total, and carotenoid concentrations in the leaves were expressed in mg g^{-1} of fresh matter.

Chlorophyll fluorescence was evaluated in the third leaf, counted from the apex of the main branch of the plant, performed on mature leaves and free from any pest and/or disease attacks with the OS5p pulse-modulated fluorimeter from Opti Science, using the Fv/Fm protocol. This protocol was performed after adaptation of the leaves to the dark for a period of 30 min, using a clip of the device to ensure that all the acceptors were oxidized, that is, with the reaction centers open.

The data were subjected to the Shapiro-Wilk normality test at $p \leq 0.05$. Subsequent analysis of variance was performed at $p \leq 0.05$ and, in cases of significance, linear and quadratic regression analysis was performed using the statistical program SISVAR (Ferreira, 2019). In case of significance of the interaction between factors, TableCurve 3D software was used to obtain response surfaces.

Results and Discussion

There was significant interaction between electrical conductivity of irrigation water (ECw) and salicylic acid (SA) concentrations for all photosynthetic pigments (Table 2).

The chlorophyll a of soursop plants (Figure 2A) irrigated with water of 1.2 dS m^{-1} and subjected to a concentration of 1.4 mM stood out with a higher value (1202.25 mg g^{-1} FM), corresponding to an increase of 8.5% (94.2 mg g^{-1} FM) compared to plants irrigated with the same ECw but without application of SA (0 mM). On the other hand, SA concentrations above 1.4 mM associated with increased ECw

Table 2. Summary of the analysis of variance for chlorophyll a, (Chl a), chlorophyll b (Chl b), chlorophyll total (Chl t) and carotenoids (Car) of soursop irrigated with saline water and subjected to foliar application of salicylic acid, at 480 days after transplantation

Source of variation	DF	Mean squares			
		Chl a	Chl b	Chl t	Car
Salinity levels (SL)	4	232051.2**	253259.6**	944500.8**	15483.3*
Linear regression	1	23.51ns	49402.5ns	51579.6ns	21925.1*
Quadratic regression	1	861130.3**	732371.7**	3181796.4**	1881.1ns
Salicylic acid (SA)	3	602536.3**	402870.8**	1923131.3**	2629.4ns
Linear regression	1	531463.7*	579637.2**	2221153.6*	2363.1ns
Quadratic regression	1	451499.1**	471774.2*	1846288.5**	915.9ns
Interaction (SL×SA)	12	273229.9**	297714.6**	950935.6**	18314.01**
Blocks	2	12847.6ns	39522.8ns	64872.5ns	630.7ns
Residual	32	13169.3	48717.1	78514.6	5671.8
CV (%)		11.35	28.23	17.64	21.82

ns, *, ** - Respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; CV - Coefficient of variation

promoted reduction of Chl a, with the lowest value (665.48 mg g^{-1} FM) obtained in plants subjected to 3.6 mM of SA and irrigated with water of 4.0 dS m^{-1}.

A reduction in Chl a concentration was observed in plants irrigated with water of the highest ECw (4.0 dS m^{-1}) and sprayed with SA at concentration of 3.6 mM. The exposure of plants to salt stress compromises physiological, biochemical, and molecular processes, due to the increase in the generation of reactive oxygen species (ROS), which damage cellular components and cause degradation of chlorophyll and lipid peroxidation of the membrane, thus reducing membrane fluidity and selectivity (Taïbi et al., 2016). However, foliar application of salicylic acid at concentration of 1.4 mM increased the Chl a of soursop, mitigating the deleterious effects of salinity on this variable.

Salicylic acid is a plant hormone that plays various physiological roles in plants and increases the activity of antioxidant enzymes such as peroxidases, superoxide dismutases, and catalases, contributing to the elimination of ROS and reducing chlorophyll degradation (Azad et al., 2021).

Salicylic acid up to an estimated concentration of 1.4 mM incremented Chl b and Chl t, regardless of the electrical conductivity of irrigation water (Figures 2B and C). Plants subjected to a SA concentration of 1.4 mM and irrigated with water of 1.5 dS m^{-1} obtained higher values of Chl b (444.4 mg g^{-1} FM) and Chl t (1492.0 mg g^{-1} FM). Soursop plants irrigated with water of 1.5 dS m^{-1} and subjected to SA concentration of 1.4 mM increased their Chl b and Chl t by 6.9% (28.6 mg g^{-1} FM) and 2.6% (37.8 mg g^{-1} FM), respectively, compared to those cultivated with ECw of 1.5 dS m^{-1} and without application of SA (0 mM). The beneficial effect of salicylic acid on the synthesis of photosynthetic pigments may be related to the ability of salicylic acid to improve enzymatic and photosynthetic activities, while also maintaining the balance between the production and elimination of ROS (Batista et al., 2019).

The results obtained in this study corroborate those reported by Mahmoud et al. (2021), in a study with Valencia orange (*Citrus sinensis* L. Osbeck), in which these authors found that foliar spraying with salicylic acid at a concentration of 50 mM promoted increments in the Chl a, Chl b and Chl t of plants under salt stress (60 mM of NaCl).

Foliar spraying with salicylic acid at an estimated concentration of 1.4 mM also mitigated the deleterious effects of salinity on carotenoid concentration (Figure 2D). Plants sprayed with SA at a concentration of 1.4 mM and irrigated with ECw of 1.5 dS m^{-1} reached the highest value of Car (249.2 mg g^{-1} FM), corresponding to increase of 4.44% (10.6 mg g^{-1} FM) compared to those irrigated with the lowest salinity level (0.8 dS m^{-1}) and without SA application.

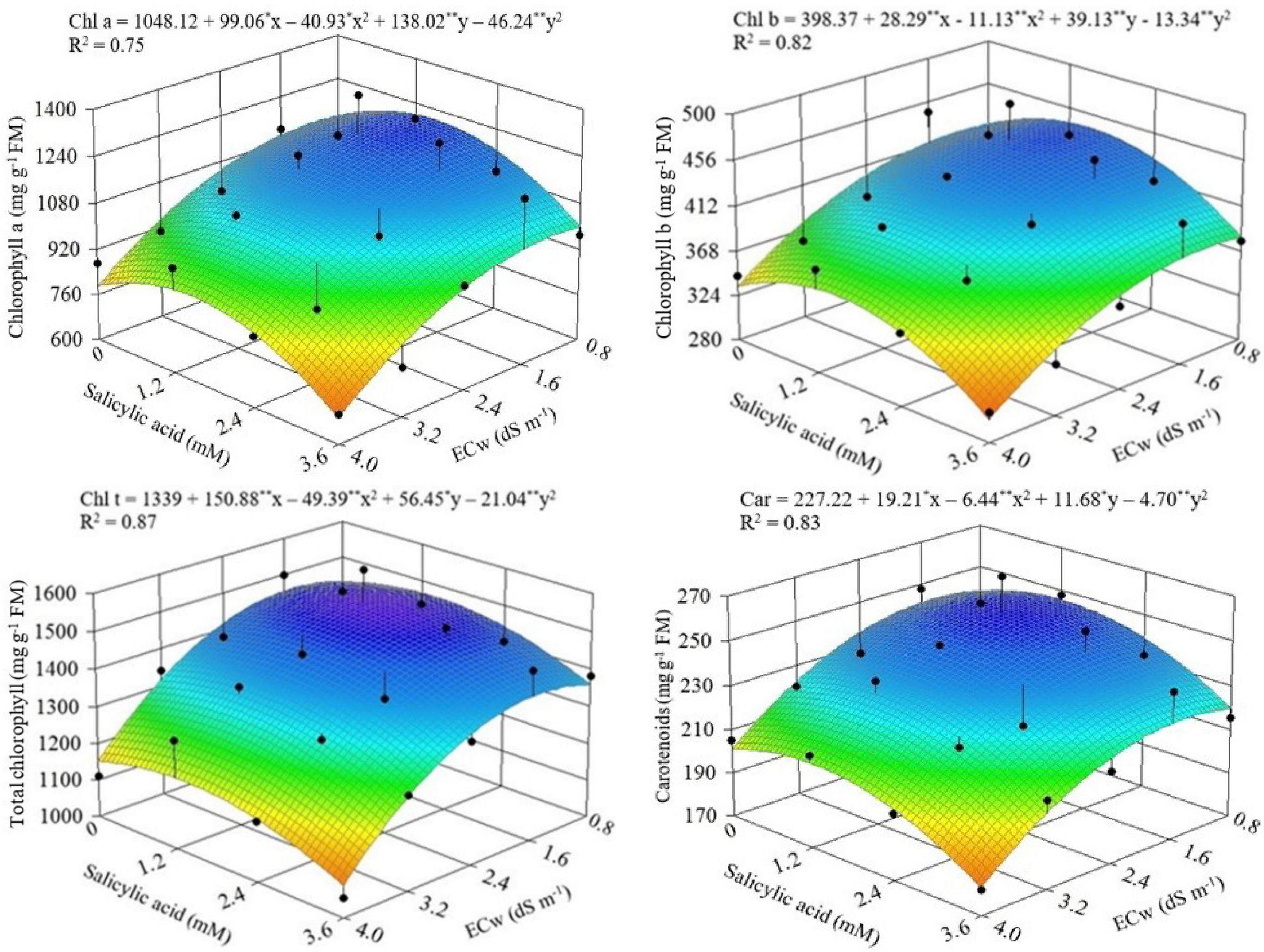
According to Lee et al. (2014), salicylic acid can increase RuBisCO activity, potassium absorption, and ATP content, maintaining an optimal K^+/Na^+ ratio in plants, thus favoring a better tolerance to salt stress. K^+ has an important role in the maintenance of cell turgor, in the opening and closing of stomata, and the control of the photosynthesis process.

The concentrations of chlorophyll a, chlorophyll b, and carotenoids found in the present study corroborate those obtained by Veloso et al. (2020) in a study conducted with soursop under salt stress (1.6 to 4.0 dS m^{-1}), in which the highest concentrations of Chl a (1303.12 mg g^{-1} FM), Chl b (363.0 mg g^{-1} FM) and Car (411.03 mg g^{-1} FM) were found in plants irrigated with water of 1.6 dS m^{-1}.

The interaction between ECw and salicylic acid concentrations (Table 3) did not significantly influence any of the chlorophyll a fluorescence variables. Individually, the ECw significantly affected all variables under study. On the other hand, salicylic acid concentrations alone had no significant effect on the chlorophyll fluorescence of soursop at 480 days after transplanting. It is worth mentioning that the effect of salicylic acid depends on several factors, including the concentration of the solution, the plant species, the stage of development and the mode of application.

The increase in the electrical conductivity of irrigation water caused positive linear effect on the initial fluorescence (Figure 3A), equal to 2.27% per unit increase in ECw. Plants irrigated with water of the highest salinity (4.0 dS m^{-1}) had an increase of 7.13% (45.9) compared to those cultivated with ECw of 0.8 dS m^{-1}. The increase in Fo is indicative of damage to the photosynthetic apparatus caused by salt stress, since this variable indicates the loss of light energy, a situation that occurs in a state of oxidation of the quinone (primary electron receptor) in the reaction center (P680), hindering the transfer of energy from photosystem II (Dias et al., 2021).

Sá et al. (2021), evaluating the photosynthetic efficiency of sugar apple (*Annona squamosa* L.) under salt stress (ECw varying between 0.8 and 3.0 dS m^{-1}), found an increase (7%) in



X and Y - ECw and salicylic acid, respectively; *, ** - Significant at $p \leq 0.05$ and 0.01 by F test

Figure 2. Response surface for chlorophyll a - Chl a (A), chlorophyll b - Chl b (B), total chlorophyll - Chl t (C) and carotenoids - Car (D) of soursop cv. Morada Nova as a function of the interaction between the electrical conductivity of the water - ECw and the concentrations of salicylic acid, at 480 days after transplantation

Table 3. Summary of the analysis of variance for initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm) of soursop irrigated with saline water and subjected to foliar application of salicylic acid, at 480 days after transplantation

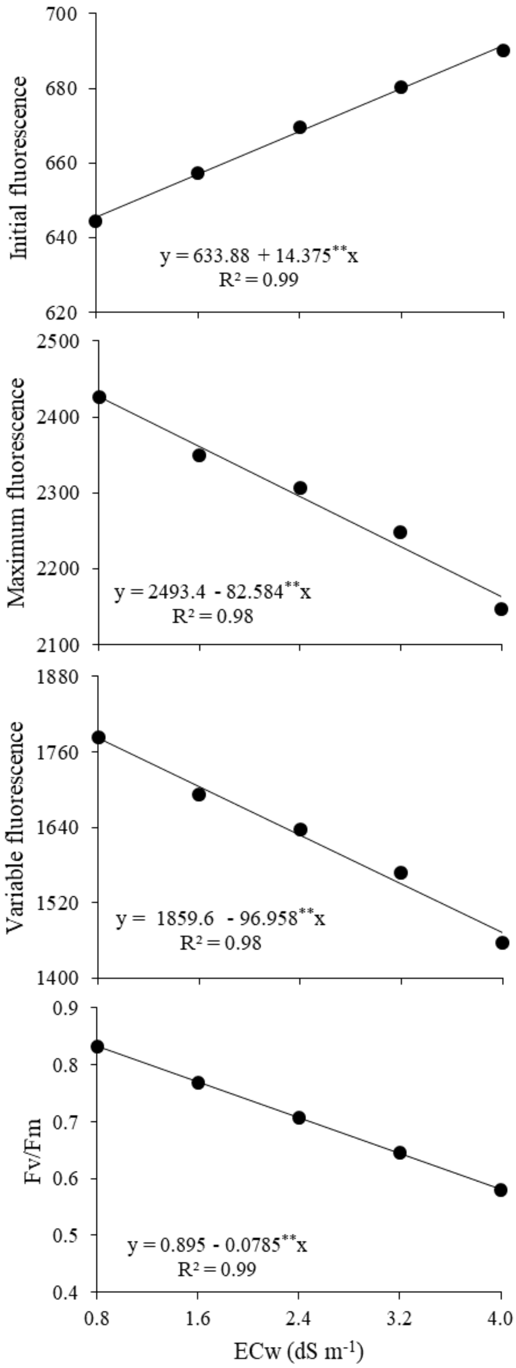
Source of variation	DF	Mean squares			
		Fo	Fm	Fv	Fv/Fm
Salinity levels (SL)	4	3981.2^{**}	133585.4^{*}	182939^{**}	$5.1 \times 10^{-3**}$
Linear regression	1	15870^{**}	523776.5^{**}	721990.5^{**}	$2.1 \times 10^{-2**}$
Quadratic regression	1	54.9^{ns}	3259.5^{ns}	2468.7^{ns}	1×10^{-5ns}
Salicylic acid (SA)	3	78.9^{ns}	7369.1^{ns}	6837.2^{ns}	1.1×10^{-3ns}
Linear regression	1	21.9^{ns}	12416.3^{ns}	13480.4^{ns}	3×10^{-4ns}
Quadratic regression	1	126.2^{ns}	6489.6^{ns}	4806.2^{ns}	7×10^{-6ns}
Interaction (SL x SA)	12	57.3^{ns}	4169.8^{ns}	4501.8^{ns}	1.4×10^{-3ns}
Blocks	2	150.6^{ns}	20289.6^{ns}	19129.9^{ns}	4.8×10^{-3ns}
Residual	32	187.6	42226.5	42099.4	$6.1 \times 10^{-3**}$
CV (%)		6.05	8.95	12.61	6.48

ns, *, ** - Respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; CV - Coefficient of variation

the initial fluorescence (Fo) of plants when they were irrigated with water of the highest salinity, when comparing the Fo of plants irrigated with water of 3.0 dS m^{-1} to that of those cultivated under salinity of 0.8 dS m^{-1}.

Unlike the effect observed on Fo (Figure 3A), the maximum fluorescence was reduced with the increasing salinity of irrigation water (Figure 3B). Plants irrigated with water of the highest salinity (4.0 dS m^{-1}) showed a reduction of 10.9% (264.3), compared to those cultivated with ECw of 0.8 dS m^{-1}. The reduction in Fm may be an indication that there was low efficiency in quinone photoreduction and electron flow between photosystems, which results in low PSII activity in the thylakoid membrane, directly influencing the electron flow between photosystems (Dias et al., 2018a).

It was observed in the present study that salt stress reduced the production of photosynthetic pigments of soursop (Figure 2),



** - Significant at $p \leq 0.01$ by F test

Figure 3. Initial fluorescence - Fo (A), maximum fluorescence - Fm (B), variable fluorescence - Fv (C), and quantum efficiency of photosystem II - Fv/Fm (D) of soursop as a function of the electrical conductivity of irrigation water - ECw, at 480 days after transplantation

and the excess of salts induces the degradation of β-carotene, which also decreased the concentration of carotenoids, which are integrated components of the thylakoid membranes, acting in the absorption and transfer of light to chlorophyll, thus compromising chlorophyll a fluorescence (Silva et al., 2017).

The variable fluorescence (Figure 3C) of soursop was negatively affected by the increase in ECw. Plants subjected to irrigation with water of 0.8 dS m^{-1} had Fv of 1782.03, while the lowest value (1471.76) was verified in plants irrigated with ECw of 4.0 dS m^{-1}, that is, there was a reduction in Fv of 310.3 (17.41%) under the highest ECw (4.0 dS m^{-1}). Fv reflects the plant's ability to transfer energy from electrons ejected from pigment molecules to the formation of the reducing agent NADPH, ATP, and reduction of ferredoxin, consequently leading to a greater capacity of CO_2 assimilation in the biochemical phase of photosynthesis (Baker, 2008; Dias et al., 2018b). Reduction of Fv indicates that the photosynthetic apparatus was damaged by salt stress, compromising the photosystem II, with negative effects on the photosynthetic process.

Similar results were observed by Ferreira et al. (2021) in a study conducted with custard apple (*Annona squamosa* L.) under salt stress (0.8 and 3.0 dS m^{-1}), in which they found reduction of 18.98% in the Fv of plants irrigated with the highest ECw (3.0 dS m^{-1}), at 695 DAT.

As observed for Fv (Figure 3C), the Fv/Fm ratio of soursop also showed a negative linear effect with increasing electrical conductivity of irrigation water (Figure 3D). Plants irrigated with ECw of 4.0 dS m^{-1} were negatively affected, with a reduction of 30.2% (0.251) in Fv/Fm in comparison to plants under ECw of 0.8 dS m^{-1}. In addition, it can be observed (Figure 3D) that the highest Fv/Fm value (0.832) was obtained in plants grown under the lowest ECw (0.8 dS m^{-1}), while plants irrigated with ECw of 4.0 dS m^{-1} showed the lowest value (0.581). When the photosynthetic apparatus is intact, Fv/Fm values vary between 0.75 and 0.85 (Dias et al., 2018b).

In general, it was observed in the present study that foliar application of salicylic acid at the concentration of 1.4 mM mitigated the deleterious effects of salinity on the photosynthetic pigments of soursop cv. Morada Nova when irrigated with water of up to 1.5 dS m^{-1}, increasing chlorophyll (Chl a, Chl b and Chl t) and carotenoid concentrations (Figure 2). However, with applications of salicylic acid at higher concentrations, a negative effect was observed on the variables analyzed. It is noteworthy that salicylic acid's beneficial effect depends on several factors, including the solution concentration, that is, at high concentrations, SA can exert a toxic effect on plants. Regarding chlorophyll a fluorescence, it was observed that the salinity of irrigation water negatively affected all variables. Despite that, the quantum efficiency of the photosystem II of soursop was not compromised when plants were irrigated with water of up to ECw = 1.8 dS m^{-1}, since the Fv/Fm was within the range from 0.75 to 0.85.

Conclusions

1. Foliar application of 1.4 mM salicylic acid mitigates the effects of salt stress on chlorophyll a, chlorophyll b, chlorophyll total, and carotenoids of soursop when irrigated with water of up to 1.5 dS m^{-1}.

2. Spraying with salicylic acid at concentrations above 1.4 mM intensifies the deleterious effects of irrigation water salinity on photosynthetic pigments.

3. Chlorophyll a fluorescence was not influenced by salicylic acid sprays up to the concentration of 3.6 mM.

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