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Research Article
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Hydroponic cultivation of okra using brackish water and salicylic acid[1]

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ABSTRACT - Cultivation of vegetables in a hydroponic system associated with the use of salicylic acid has been a viable alternative in mitigating salt stress. Therefore, the objective of the present study was to evaluate the effects of foliar application of salicylic acid on okra cv. Canindé in a hydroponic system with brackish water. The experiment was carried out in a greenhouse using a Nutrient Film Technique (NFT) hydroponic system in Pombal, Paraíba, Brazil, adopting a completely randomized design in a split-plot arrangement. The main plots consisted of four levels of electrical conductivity of the nutrient solution (ECns: 3.0, 5.0, 7.0, and 9.0 dS m^{-1}), while the subplots consisted of four concentrations of salicylic acid (SA: 0, 1.2, 2.4, and 3.6 mM), with four replicates and two plants per plot. Electrical conductivity of the nutrient solution above 3.0 dS m^{-1} compromised the physiological and production performance of okra cv. Canindé in hydroponic cultivation, reducing maximum and initial fluorescence, electron transport rate, biomass accumulation, root volume, as well as the number, mass, and size of fruits per plant. Application of salicylic acid at concentrations between 1.6 and 2.4 mM mitigates the effects of salt stress on post-harvest quality attributes, resulting in increases in soluble solids content, titratable acidity, and ascorbic acid in okra fruits under nutrient solution salinity levels of up to 9.0 dS m^{-1}.

Keywords: *Abelmoschus esculentus* L. Moench. Salt stress. Phytohormone.

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INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench), a species native to Africa, is a monocot herbaceous belonging to the Malvaceae family, with great nutritional importance for having considerable amounts of fiber and mineral salts, such as iron, copper, calcium, and phosphorus, besides containing vitamins A, C and B-complex (Oliveira *et al*., 2020; Reswari *et al*., 2025).

The Northeast region of Brazil is characterized by the quantitative scarcity of water resources of good quality, resulting from the high evaporation rates and low rainfall. Therefore, the expansion of irrigated agriculture is limited, due to the occurrence of water sources with high concentrations of salts (Lima *et al*., 2020), which makes conventional cultivation in soil unfeasible in many cases, causing osmotic and ionic effects on plants and leading to soil salinization.

Water and/or soil salinity causes negative effects on plants, reducing the absorption of water and nutrients, due to the low osmotic potential, affecting photosynthetic efficiency, production and quality of fruits, making their commercialization unfeasible (Santos *et al*., 2020).

Among the production systems for the cultivation of vegetables, hydroponics stands out as a promising alternative, enabling cultivation in regions that have water sources with high concentrations of salts (Sausen *et al*., 2020). The viability of using brackish waters in hydroponic cultivation with vegetables is associated with the absence of matric potential and has been widely proven by several studies (Oliveira *et al*., 2022; Silva *et al*., 2021; Sá *et al*., 2024).

Another alternative that can enhance the cultivation of vegetable species using brackish water is the use of plant growth regulators, particularly foliar application of salicylic acid (Sá *et al*., 2024), which is a naturally produced phenolic compound that acts on the signaling and activation of genes promoting plant defense mechanism against abiotic and biotic stresses, involved in the regulation of various physiological and biochemical processes, such as transpiration, photosynthesis, stomatal opening, germination, and ionic absorption (Santos *et al*., 2025). The beneficial effect of salicylic acid on plants under salt stress in hydroponic systems has been observed in melon – *Cucumis melo* L. (Oliveira *et al*., 2022) and nasturtium - *Tropaeolum majus* L. (Santos *et al*., 2025).

In view of this scenario, it is hypothesized that the foliar application of salicylic acid is capable of attenuating the effects of salt stress on the physiological and production performance and post-harvest quality of okra cultivated in a hydroponic system.

In view of the above, the objective of this study was to evaluate the effects of foliar application of salicylic acid on okra cv. Canindé in a hydroponic system with brackish nutrient solutions.

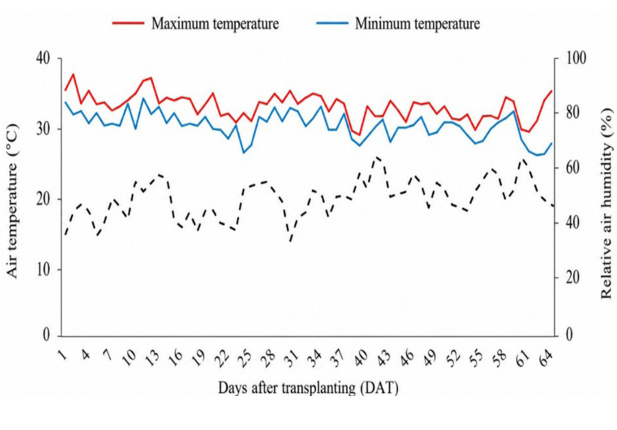
MATERIAL AND METHODS

The experiment was conducted from January 27 to March 16, 2022 under greenhouse conditions at the Center for Science and Agri-Food Technology of the Federal University of Campina Grande (UFCG), Pombal, PB, Brazil, geographically located at 6° 46’ 8” South and 37° 47’ 45” West, with an altitude of 184 m and average annual rainfall of 700 mm. Data on maximum and minimum temperature and relative humidity were collected daily inside the greenhouse using a digital thermohygrometer (Figure 1).

Treatments consisted of four levels of electrical conductivity of the nutrient solution - ECns (3.0, 5.0, 7.0, and 9.0 dS m^{-1}) and four concentrations of salicylic acid - SA (0, 1.2, 2.4, and 3.6 mM) distributed in a completely randomized design, in a split-plot arrangement, with ECns levels as the plots represented by individual cultivation bench and the SA concentrations as the subplots represented by the plants on the same bench, with four replicates and two plants per experimental plot. The salicylic acid concentrations used were based on a study conducted by Oliveira *et al*. (2022) with the melon crop (*Cucumis melo* L.).

The experiment was conducted using seeds of okra, cv. Canindé, a hybrid from ISLA® (Porto Alegre, Brazil). This cultivar has a cycle of approximately 80 days in soil, with tall size, fruits with five-ridged cross section, with a length between 10 and 15 cm and a diameter ranging from 18 to 20 mm, in addition to excellent post-harvest conservation, resistance to the Yellow Vein Mosaic Virus – YVMV and wide adaptability to different cultivation regions.

Figure 1 - Daily data on maximum and minimum air temperatures and average relative air humidity during the experimental period from January 27 to March 16, 2022



The nutrient solution adopted was based on the formulation of Hoagland and Arnon (1950), containing N, P, K, Ca, Mg, S, B, Mn, Zn, Cu, Mo and Fe at concentrations of 210, 31, 234, 200, 48, 64, 0.5, 0.5, 0.05, 0.02, 0.01, and 5 mg L^{-1}, respectively. Monopotassium phosphate (KH_2PO_4 – 136.09 g), potassium nitrate (KNO_3 – 101.10 g), calcium nitrate ($Ca(NO_3)_2.4H_2O$ – 236.15 g) and magnesium sulfate ($MgSO_4.7H_2O$ – 146.49 g) were used as macronutrient sources to prepare 1000 L of the solution. Micronutrients were provided by boric acid (H_3BO_3 – 3.10 g), manganese sulfate ($MnSO_4.4H_2O$ – 1.70 g), zinc sulfate ($ZnSO_4.7H_2O$ – 0.22 g), copper sulfate ($CuSO_4.5H_2O$ – 0.75 g), ammonium molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$ – 1.25 g), as well as ferrous sulfate ($FeSO_4$ – 13.9 g) and EDTA-Na (13.9 g).

The solution was prepared in local-supply water (0.3 dS m^{-1}), obtaining electrical conductivity of 2.1 dS m^{-1} after the preparation of the nutrient solution. The saline nutrient solutions were prepared with the addition of non-iodized sodium chloride (NaCl), calcium chloride ($CaCl_2.2H_2O$), and magnesium chloride ($MgCl_2.6H_2O$) in an equivalent ratio of 7:2:1, respectively. The irrigation waters were prepared considering the relationship between ECw and salt concentration, according to Eq. 1:

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

Where:

Q = Sum of cations ($mmol_c$ L^{-1}); and ECw = Desired electrical conductivity after discounting the electrical conductivity of the nutrient solution – ECns (2.1 dS m^{-1}).

Okra cv. Canindé was sown in disposable 50 mL cups, containing one seed each, using coconut fiber substrate previously washed with local-supply water. A nutrient solution with a concentration of 50% was used from germination to the emergence of the second pair of true leaves, and 14 days after sowing (DAS) the coconut fiber was removed, and the plants were transplanted directly into the hydroponic profiles. The plants were grown with vertical staking system in order to leave the stem erect with nylon twine and a nutrient solution with 100% concentration.

The hydroponic system was of the Nutrient Film Technique - NFT type, made with a PVC pipe of 100 mm in diameter and six meters in length, composed of four subsystems spaced 0.8 m apart, each of which with three channels spaced 0.4 m apart. In the channels, the spacing was 0.5 m between plants and 1.0 m between treatments.

The channels were supported by trestles at a height of 0.6 m with a slope of 4% for the flow of the nutrient solution. A 150 L polyethylene recipient was placed at the lowest level of each bench of the hydroponic system to collect and conduct the nutrient solution to the channels. The nutrient solution was pumped to the channels by a 35 W pump with an average flow rate of 3 L min^{-1}. Nutrient solution circulation was programmed by a timer, with an intermittent flow of 15 min during the day and night.

The nutrient solution was completely replaced every eight days, with daily verification of electrical conductivity and pH. The ECns was adjusted whenever necessary by adding local-supply water with ECw of 0.3 dS m^{-1}, always keeping the ECns according to the treatments and the pH between 5.5 and 6.5 by adding 0.1 M KOH or HCl.

Salicylic acid concentrations were prepared by dissolving salicylic acid A.R. in 30% ethyl alcohol (99.5%) and 0.05% Haiten®, a nonionic adhesive spreader used to break surface tension and improve absorption by okra leaves.

Salicylic acid applications were carried out 48 hours after inserting the plants into the hydroponic profiles and 72 hours before the beginning of the treatments (using the respective saline nutrient solutions) for acclimatizing the plants. The applications were carried out at 5:00 p.m., manually with a spray bottle, aiming to moisten the total area of the leaves (adaxial and abaxial sides) according to the treatments, applying on an average of 19 mL per plant, at an eight-day interval, in a total of six applications. A plastic canvas structure was used to avoid the drift of the solution between the plants. The plants were monitored and phytosanitary practices were carried out whenever necessary.

At 50 days after transplanting (DAT), chlorophyll *a* fluorescence was evaluated through initial fluorescence (F_0), maximum fluorescence (Fm), variable fluorescence (Fv), maximum quantum efficiency of photosystem II (Fv/Fm), initial fluorescence before saturation pulse (Fs), maximum fluorescence after adaptation to saturated light (Fms), effective quantum yield of photosystem II (Y), electron transport rate (ETR). Chlorophyll *a* fluorescence in the dark phase was measured in leaves of the middle third, fully expanded and pre-adapted to the dark for 30 min, using a pulse-modulated fluorometer (OS5p model - Opti Science). The light pulse used was low-intensity modulated red (0.03 μmol m^{-2} s^{-1}) and then a saturated actinic light pulse (>6000 μmol m^{-2} s^{-1}). Subsequently, the determinations were carried out under light conditions, using the Yield protocol, applying an actinic lighting source with a saturating multi-flash pulse, coupled to a photosynthetically active radiation determination clip (PAR-Clip).

At the end of the okra cycle (63 DAT), the plants were removed from the hydroponic profiles and then separated into different parts (stem, leaves and root). The material was placed in paper bags and dried in an oven with forced air ventilation at a temperature of 65 °C for 72 hours. Subsequently, the material was weighed to obtain leaf dry biomass (LDB, g per plant) and stem dry biomass (STDB, g per plant), which were added to obtain shoot dry biomass (SHDB, g per plant), in addition to root dry biomass (RDB, g per plant). Total dry biomass (TDB, g per plant) was obtained by the sum of LDB, STDB and RDB. Root volume (cm^3) was measured in a graduated cylinder containing a known volume of water. The difference between two readings, before and after submerging the roots, directly provided their volume through the unit of equivalence (1 mL = 1 cm^3).

Harvesting began at 29 DAT, when okra fruits reached the point of harvest, which occurred between 4 to 5 days after anthesis, when they were 10 to 15 cm long. Immediately after harvest, the number of fruits per plant (NFP, unit), fresh fruit mass (FFM, g per plant), average fruit mass (AFM, g per fruit), average fruit length (AFL, cm), and average fruit diameter (AFD, mm) were evaluated. FFM was determined on a semi-analytical scale with a precision of 0.01 g. AMF was obtained by the ratio between fresh mass and the total number of fruits per plant.

After harvest, the fruits were stored in a freezer at a temperature of -14 ºC for seven days. To determine the post-harvest quality, three okra fruits per treatment were cut and crushed in a blender to obtain the extract. After crushing, 50 mL was removed to determine the hydrogen potential (pH), soluble solids (SS, ºBrix), titratable acidity (TA, %), total soluble sugars (TSS, %), and ascorbic acid (AA, mg $100g^{-1}$ of pulp) (Instituto Adolfo Lutz, 2008).

Total soluble solids were determined in the pulp of the unpeeled fruits, using a digital refractometer with automatic temperature compensation, whose readings were performed in triplicate. Hydrogen potential was determined with the addition of 3 g of fruit extract and 47 mL of distilled water, in triplicate, using a benchtop pH meter previously calibrated with buffer solutions of pH 4.0 and 7.0.

Total titratable acidity was determined by titration with 0.1 N NaOH, according to the methodology described by Instituto Adolfo Lutz (2008). Samples of 3 g of the extract were placed in 125 mL beaker in triplicate and diluted in 47 mL of distilled water under stirring. Subsequently, phenolphthalein drops were added as an indicator, and titration was performed until the appearance of persistent pink color. Acidity was expressed in mL of 1 N NaOH solution per 100 g of pulp obtained by Eq. 2.

$$TA = \frac{V \times f \times 100}{P \times c} \quad (2)$$

Where:

TA = total titratable acidity (%);

V = volume of sodium hydroxide used in titration (mL)

f = solution factor

P = sample weight (g)

c = NaOH solution correction

Total soluble sugars were determined according to Yemm and Willis (1954). Samples of 3 g were macerated in distilled water, and the volume was adjusted to 100 mL. Aliquots of the extract were reacted with anthrone, subjected to a water bath at 100 ºC for 3 minutes, and the reading was performed in a spectrophotometer (UV/VIS Digital Spectrophotometer - UV1720) at 620 nm.

Ascorbic acid levels were obtained by titration. 3.0 g of the sample was weighed, then titration was performed with the 2-6-dichlorophenol-indophenol (DCPIP) solution until a pink color was obtained, and the volume spent was recorded. The results were expressed in mg of ascorbic acid 100 g^{-1} of sample, and were obtained through Eq. 3. mg of ascorbic acid per 100 g

$$\frac{V \times F \times 100}{M} \quad (3)$$

Where:

V = volume of DCPIP used to titrate the sample (mL)

F = solution factor

M = sample mass (g)

The data obtained were subjected to the normality test (Shapiro Wilk), and then analysis of variance was performed using the F test at 0.05 probability level. When the F test was significant, polynomial regression analysis (linear and quadratic) was performed for the saline nutrient solution and for the salicylic acid concentrations, using the statistical software SISVAR – ESAL version 5.7. SigmaPlot software was used to construct the response surface curves in cases in which there was a significant interaction between the factors.

RESULTS AND DISCUSSION

There was a significant effect of the electrical conductivity of the nutrient solution (ECns) on the maximum fluorescence (Fm), variable fluorescence (Fv) and electron transport rate (ETR) of okra cv. Canindé (Table 1). Salicylic acid did not significantly influence any of the variables evaluated. In addition, no significant effect of the interaction (ECns × SA) on initial fluorescence (F_0), quantum efficiency of photosystem II in the dark phase (Fv/Fm), initial fluorescence before the saturation pulse (Fs), maximum fluorescence after adaptation to saturated light (Fms), and quantum efficiency of photosystem II in the light phase (YII) was observed at 50 days after transplantation.

Table 1 - Summary of the analysis of variance for initial fluorescence (F_0), maximum fluorescence (Fm), variable fluorescence (Fv), quantum efficiency of photosystem II in the dark phase (Fv/Fm), initial fluorescence before the saturation pulse (Fs), maximum fluorescence after adaptation to saturated light (Fms), quantum efficiency of photosystem II in the light phase (YII) and electron transport rate (ETR) of okra cv. Canindé cultivated under saline nutrient solution (ECns) and salicylic acid (SA) concentrations in a hydroponic system, 50 days after transplanting

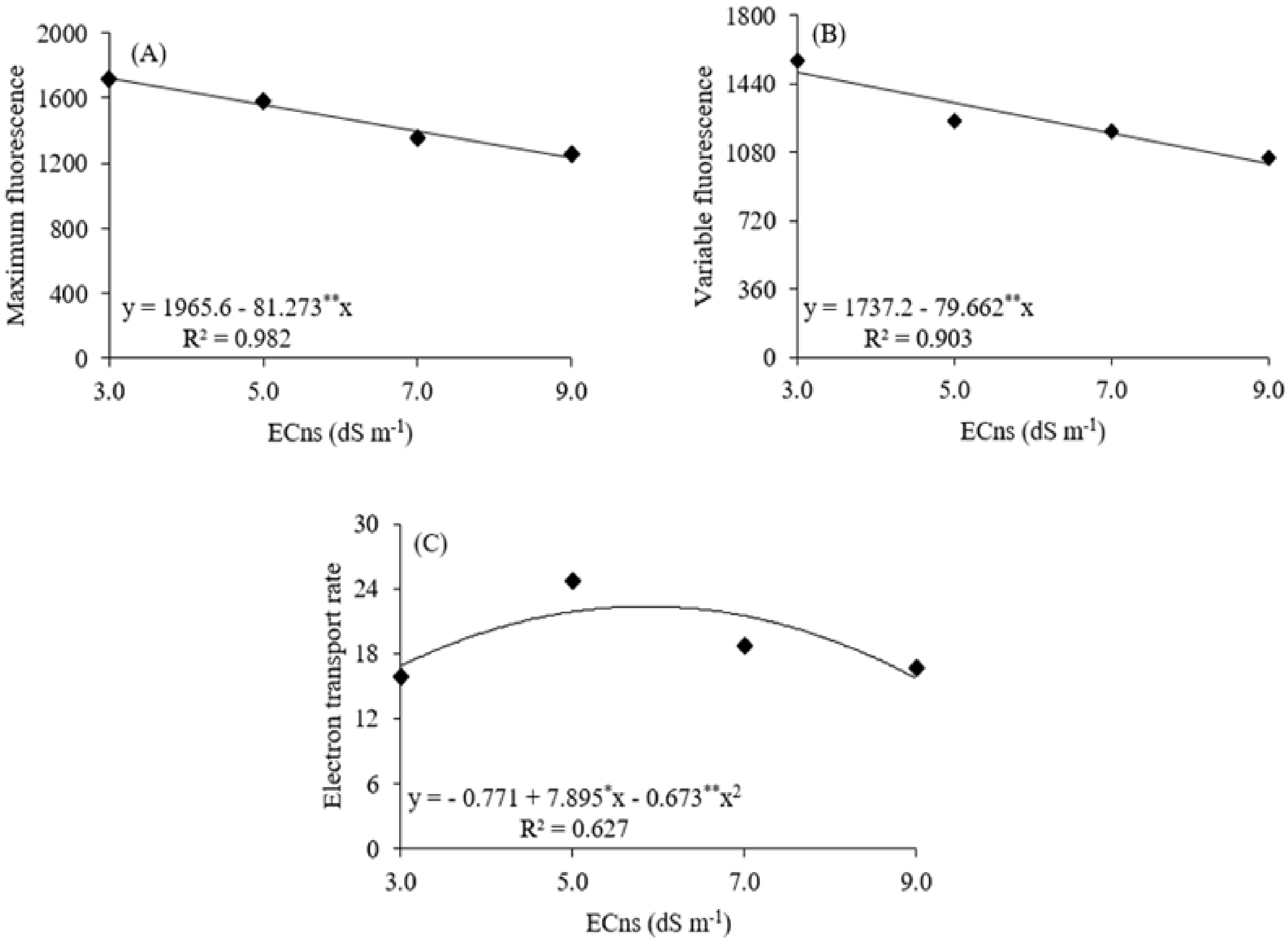
Sources of Variation	DF	Mean squares			
		F_0	Fm	Fv	Fv/Fm
Saline nutrient solution (ECns)	3	1407.02^{ns}	537665.39**	561882.93*	0.00045^{ns}
Linear regression	1	-	1585268.87**	1522987.67**	-
Quadratic regression	1	-	3897.00^{ns}	95007.50^{ns}	-
Residual 1	6	3128.12	2773.2	6617.27	0.00025
Salicylic acid (SA)	3	1575.06^{ns}	1280.51^{ns}	6018.78^{ns}	0.00025^{ns}
Linear regression	1	-	-	-	-
Quadratic regression	1	-	-	-	-
Interaction (ECns × SA)	9	1113.00^{ns}	2761.16^{ns}	2485.24^{ns}	0.00018^{ns}
Residual 2	26	15646.54	2787.54	10263.94	0.00024
CV 1(%)		6.28	3.56	6.46	2.04
CV 2(%)		6.75	3.57	8.05	2.02
		Fs(1)	Fms(1)	Y_{II}	ETR
Saline nutrient solution (ECns)	3	862.31^{ns}	9685.63^{ns}	0.0029^{ns}	190.04*
Linear regression	1	-	-	-	8.70^{ns}
Quadratic regression	1	-	-	-	349.38**
Residual 1	6	723.85	6582.14	0.0058	25.76
Salicylic acid (SA)	3	256.11^{ns}	2674.22^{ns}	0.0020^{ns}	24.34^{ns}
Linear regression	1	-	-	-	-
Quadratic regression	1	-	-	-	-
Interaction (ECns × SA)	9	599.37^{ns}	3025.83^{ns}	0.0016^{ns}	24.34^{ns}
Residual 2	26	640.77	2419.14	0.0021	8.05
CV 1(%)		12.72	15.76	12.1	26.75
CV 2(%)		12.82	9.75	7.3	14.95

DF - degrees of freedom; CV - coefficient of variation; **significant at 0.01 probability level; *significant at 0.05 probability level; ^{not} significant; (1) data transformed into √x

The maximum fluorescence of okra plants cv. Canindé decreased linearly with the increase in the electrical conductivity of the saline nutrient solution, by 4.13% per unit increment in ECns (Figure 2A). When comparing in relative terms plants subjected to ECns of 9.0 dS m^{-1} to those cultivated with saline nutrient solution of 3.0 dS m^{-1}, a decline of 28.32% was observed. The reduction in maximum fluorescence is related to the deficiency in the photoreduction of quinone A, due to the inactivation of PSII in thylakoid membranes. This decrease affects the flow of electrons between the photosystems, influencing the photochemical activity in the leaves, since a high maximum fluorescence has effects on the transfer of energy for the formation of the reducer NADPH, ATP and reduced ferredoxin, promoting a greater capacity for CO_2 assimilation in the biochemical phase of photosynthesis (Lima *et al*., 2019).

For variable fluorescence, there was a decrease of 4.58% per unit increment in the saline nutrient solution (Figure 2B). The higher the Fv values, the greater the efficiency in transferring the energy from excited electrons to the formation of NADPH, ATP and reduced ferredoxin, reflecting a greater capacity for CO_2 assimilation in the biochemical phase of photosynthesis (Silva *et al*., 2021).

Figure 2 - Maximum fluorescence - Fm (A), variable fluorescence - Fv (B) and electron transport rate - ETR (C) of okra cv. Canindé, as a function of the electrical conductivity of the saline nutrient solution - ECns in a hydroponic system at 50 days after transplanting



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

The electron transport rate of okra plants was described by a quadratic regression model (Figure 2C), with an estimated maximum value of 22.38 at ECns of 5.9 dS m^{-1} and a minimum of 15.77 at the highest salinity level (9.0 dS m^{-1}). When comparing plants grown under ECns of 9.0 dS m^{-1} to those subjected to 3.0 dS m^{-1}, a reduction of 6.44% was observed in ETR. The high concentration of salts reduces the osmotic potential and the availability of water, compromising the activity of electron transporters and, consequently, the photosynthetic process (Tatagiba *et al*., 2014).

There was a significant effect of the saline nutrient solution on the leaf (LDB), stem (STDB), shoot (SHDB), root (RDB) and total dry biomass (TDB), and root volume (RV) of okra plants cv. Canindé (Table 2). Salicylic acid concentrations and the interaction between factors (ECns × SA) did not significantly influence any of these variables at 64 days after transplanting.

The leaf dry biomass of okra decreased linearly with the increase in the electrical conductivity of the nutrient solution (Figure 3A), by 9.05% per unit increment in ECns. When comparing in relative terms plants cultivated under ECns of 9.0 dS m^{-1} to those subjected to the lowest salinity level (3.0 dS m^{-1}), a reduction of 74.59% was observed. The reduction in leaf dry biomass accumulation is a consequence of the decrease in osmotic potential, which hinders the absorption of water and nutrients by the roots, reducing stomatal opening, interfering in the photosynthetic activity of the plant (Souza *et al.*, 2016). Similar results were found by Nascimento *et al.* (2017), in a study evaluating okra plants under conditions of salt stress in soil (ranging from 0.26 to 5.0 dS m^{-1} of electrical conductivity of the saturation extract), in which they found a reduction of 40.29% in leaf dry biomass.

Table 2 - Summary of the analysis of variance for the leaf (LDB), stem (STDB), shoot (SHDB), root (RDB) and total dry biomass (TDB) and root volume (RV) of okra cv. Canindé cultivated under saline nutrient solution (ECns) and salicylic acid (SA) concentrations in a hydroponic system, at 64 days after transplanting

Sources of Variation	DF	Mean squares					
		LDB(1)	STDB(1)	SHDB(1)	RDB(1)	TDB(1)	RV(1)
Saline nutrient solution (ECns)	3	2489.18**	11492.97**	25539.03**	1040.39**	36813.26**	59350.86**
Linear regression	1	7040.69**	32385.64**	71830.63**	2907.26**	103539.69**	154026.66**
Quadratic regression	1	184.12ns	1453.65ns	3001.52ns	66.38ns	3946.72ns	14525.52**
Residual 1	6	89.22	204.96	541.89	18.92	695.36	724.30
Salicylic acid (SA)	3	22.14ns	168.74ns	218.17ns	33.27ns	99.52ns	1419.61ns
Linear regression	1	-	-	-	-	-	-
Quadratic regression	1	-	-	-	-	-	-
Interaction (ECns × SA)	9	60.01ns	260.82ns	437.28ns	9.58ns	396.25ns	1884.78ns
Residual 2	26	119.73	450.69	954.63	22.66	1126.93	2053.04
CV 1(%)		18.33	14.95	15.43	12.38	14.27	9.35
CV 2(%)		16.24	16.73	15.64	13.7	14.49	14.2

DF - degrees of freedom; CV (%) - coefficient of variation; **significant at 0.01 probability level; not significant; (1) data transformed into √x

For stem dry biomass (Figure 3B), plants under saline nutrient solution of 3.0 dS m^{-1} reached the maximum estimated value of 88.62 g per plant, while those subjected to ECns of 9.0 dS m^{-1} expressed the lowest STDB, 18.90 g per plant. Nascimento *et al.* (2017) in a study evaluating the effects of increasing levels of electrical conductivity of water (ranging between 0.26 and 5.0 dS m^{-1}) on okra plants, also observed a reduction of 11.17% per unit increase in the electrical conductivity of water.

The shoot dry biomass of okra cv. Canindé (Figure 3C) decreased with the increase in ECns, by 9.62% per unit increase in ECns. The reduction in biomass accumulation occurs due to osmotic and ionic effects, reducing the availability of water to plants, interfering in cell expansion, inducing stomatal closure, and compromising the photosynthetic rate and consequently the growth of the plant (Lima *et al*., 2021). Oliveira *et al.* (2022), when evaluating the accumulation of shoot dry biomass of "gaúcho" melon plants under saline nutrient solution (ECns from 2.1 to 5.4 dS m^{-1}), also found a linear reduction in biomass accumulation of 8.47% per unit increment in ECns.

Okra root dry biomass decreased linearly with the increase in ECns, by 9.11% per unit increment in ECns (Figure 3D). In plants under 9.0 dS m^{-1}, the reduction was 75.27% compared to those subjected to 3.0 dS m^{-1}. Total dry biomass (Figure 3E) also showed a linear reduction, with a decrease of 9.53% per unit increase in ECns, reaching a decline of 80.09% at the highest salinity level. This reduction may be associated with limited cell expansion, leaf senescence, smaller photosynthetic area, and reduced stomatal conductance (Jia *et al*., 2018).

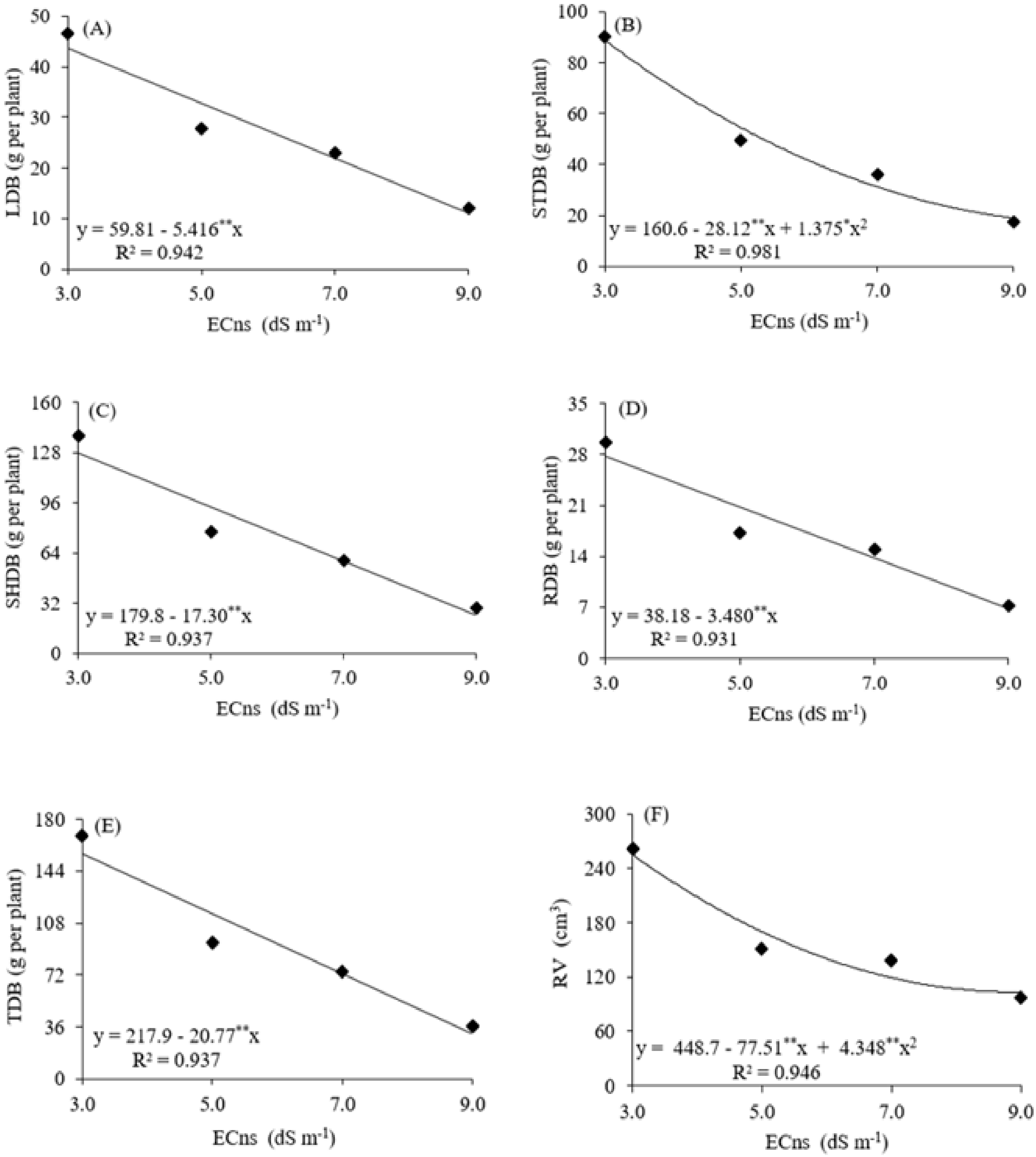
For the root volume of okra cv. Canindé (Figure 3F), the highest estimated value of 255.30 cm^3 was obtained in plants subjected to ECns of 3.0 dS m^{-1}. The lowest value of 103.27 cm^3 was found at ECns of 9.0 dS m^{-1}, with a reduction of 59.55%. The effect of salinity on the root system is due to the direct contact between the roots and the salts of the medium, causing reductions in growth and transpiration rates (Oliveira *et al*., 2022).

There was a significant effect of saline nutrient solution (ECns) on number of fruits per plant (NFP), fresh fruit mass (FFM), average fruit length (AFL) and average fruit mass per plant (AFM) of okra cv. Canindé cultivated in a hydroponic system, at 64 DAT (Table 3). Salicylic acid concentrations and the interaction between the factors (ECns × SA) did not significantly influence the production components of okra cv. Canindé, at 64 days after transplantation.

The number of fruits per plant (NFP) was reduced by 6.91% per unit increment in ECns (Figure 4A). When comparing plants subjected to ECns of 9.0 dS m^{-1} with those in the control treatment (3.0 dS m^{-1}), a reduction of 52.39% was observed in NFP. Excess salts in water inhibit the absorption of water and nutrients by plants, affecting the number of fruits. Dantas *et al*. (2022), in a study evaluating the production of zucchini, as a function of the saline nutrient solution (ECns from 2.1 to 6.6 dS m^{-1}), observed a linear reduction of 5.86% per unit increment in the levels of the saline nutrient solution.

The fresh fruit mass - FFM of okra decreased by 7.52% per unit increment in the electrical conductivity of the nutrient solution (Figure 4B). When comparing in relative terms plants subjected to ECns of 9.0 dS m^{-1} to those cultivated with saline nutrient solution of 3.0 dS m^{-1}, a decline of 58.27% was observed. The decrease in fruit mass may be related to the reallocation of energy due to the increase in the electrical conductivity of the nutrient solution, thus resulting in a reduction of metabolic energy

Figure 3 - Leaf - LDB (A), stem - STDB (B), shoot - SHDB (C), root - RDB (D) and total dry biomass - TDB (E) and root volume - RV (F) of okra cv. Canindé, as a function of the electrical conductivity of the saline nutrient solution – ECns in hydroponic cultivation, at 64 days after transplanting



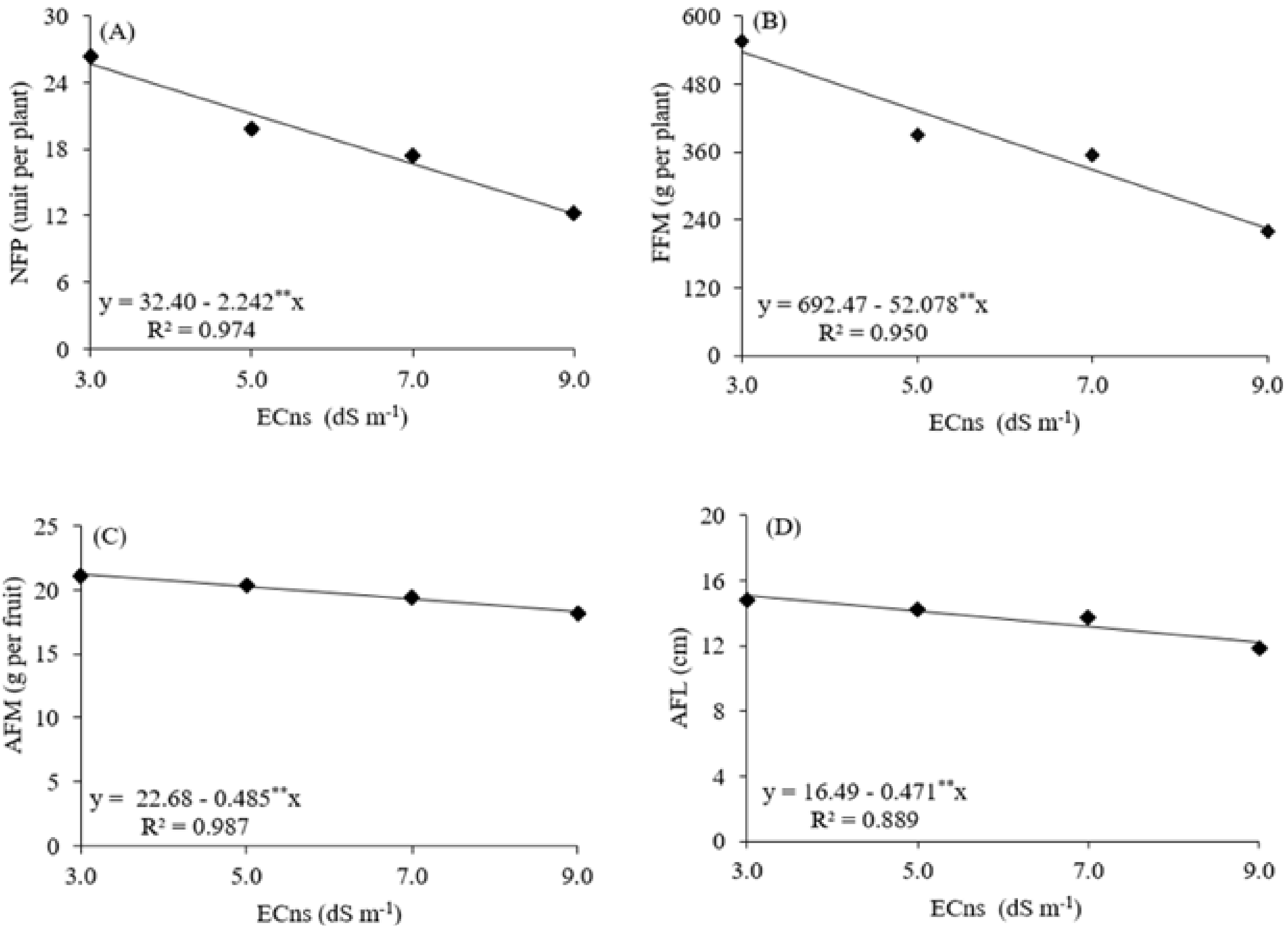
*, ** - Significant at $p \leq 0.05$ and ≤ 0.01 by the F test, respectively

Table 3 - Summary of the analysis of variance for number of fruits per plant (NFP), fresh fruit mass (FFM), average fruit mass per plant (AFM), average fruit length (AFL), and average fruit diameter (AFD) of okra cv. Canindé cultivated under saline nutrient solution (ECns) and salicylic acid (SA) concentrations in a hydroponic system, at 64 days after transplanting

Sources of Variation	Mean squares					
	DF	NFP	FFM	AFM	AFL	AFD
Saline nutrient solution (ECns)	3	412.68**	228345.33**	24.71**	19.91**	3.78^{ns}
Linear regression	1	1206.01**	650884.60**	56.12**	53.12**	-
Quadratic regression	1	4.68^{ns}	2759.65^{ns}	0.68^{ns}	5.40**	-
Residual 1	6	8.35	7101.16	2.52	0.20	1.70
Salicylic acid (SA)	3	5.95^{ns}	573.82^{ns}	0.29^{ns}	0.19^{ns}	0.27^{ns}
Linear regression	1	-	-	-	-	-
Quadratic regression	1	-	-	-	-	-
Interaction (ECns × SA)	9	5.95^{ns}	1731.03^{ns}	1.62^{ns}	0.18^{ns}	0.58^{ns}
Residual 2	26	5.79	3344.32	3.05	0.39	1.1
CV 1(%)		15.24	22.18	8.04	3.28	7.37
CV 2(%)		12.7	15.22	8.84	4.58	5.94

DF - degrees of freedom; CV (%) - coefficient of variation; **significant at 0.01 probability level; ^{ns} not significant

Figure 4 - Number of fruits per plant - NFP (A), fresh fruit mass - FFM (B), average fruit mass per plant - AFM (C) and average fruit length - AFL (D) of okra cv. Canindé, as a function of the electrical conductivity of the saline nutrient solution – ECns in hydroponic cultivation, at 64 days after transplanting



** - Significant at p ≤ 0.01 by the F test in the plants (Sousa *et al*., 2021). Modesto *et al*. (2019) reported that the electrical conductivity of the nutrient solution from 9.46 dS m^{-1} increased the earliness index of okra cv. Speedy, with no measurable benefit to production.

For the average fruit mass - AFM of okra cv. Canindé, Figure 4C shows a linear reduction of 2.13% per unit increment in ECns, corresponding to a decrease of 13.71% in plants subjected to ECns of 9.0 dS m^{-1} compared to those under saline nutrient solution of 3.0 dS m^{-1}. The reduction in okra fruit mass can be explained by the high concentration of salts in the root zone, causing reductions in photosynthesis and respiration, with changes in cell growth, resulting in a lower absorption of nutrients by the plants (Ayub *et al*., 2021). Batista *et al*. (2021) found that saline nutrient solution (between 2.5 and 8.5 dS m^{-1}) reduced the fruit production of red cherry tomato grown in a hydroponic system, with the maximum estimated value of 411.23 g per plant at salinity of 3.76 dS m^{-1}.

The average length of okra fruits was reduced with the increase in ECns (Figure 4D), by 2.86% per unit increment. When comparing plants under 9.0 dS m^{-1} with those subjected to 3.0 dS m^{-1}, a decline of 18.74% is observed. This reduction may be associated with the diversion of energy for metabolic maintenance and the redistribution of photoassimilates among plant organs (Oliveira *et al*., 2022). Despite that, the fruits of cv. Canindé were longer than 12 cm at all ECns levels, falling into Class 1A of the Companhia de Entrepostos e Armazéns Gerais de São Paulo (2022) and remaining suitable for commercialization.

According to the result of the analysis of variance (Table 4), there was a significant effect of the interaction between saline nutrient solution and salicylic acid (ECns × SA) on the hydrogen potential (pH), soluble solids (SS), titratable acidity (TA), total soluble sugars (TSS), and ascorbic acid (AA) of okra cv. Canindé. There were significant main effects of saline nutrient solution (ECns) and salicylic acid (SA) concentrations on all variables analyzed (Table 4).

Regarding the hydrogen potential of okra fruit pulp (Figure 5A), salinity of 6.4 dS m^{-1} promoted higher pH (6.48) in plants subjected to 1.8 mM of SA, while the lowest pH (5.75) was observed at 3.6 mM of SA and 3.0 dS m^{-1}. pH is an important indicator of post-harvest quality, as lower values (higher acidity) contribute to fruit conservation by inhibiting the growth of microorganisms. Thus, although higher pH values have been recorded under more saline conditions, the reduction in pH can favor the shelf life of the fruits (Oliveira *et al*., 2019). Similar results were reported by Dantas *et al*. (2022), who observed a reduction of 1.94% per unit increase in ECns, with the highest value of 6.46 at 2.1 dS m^{-1}.

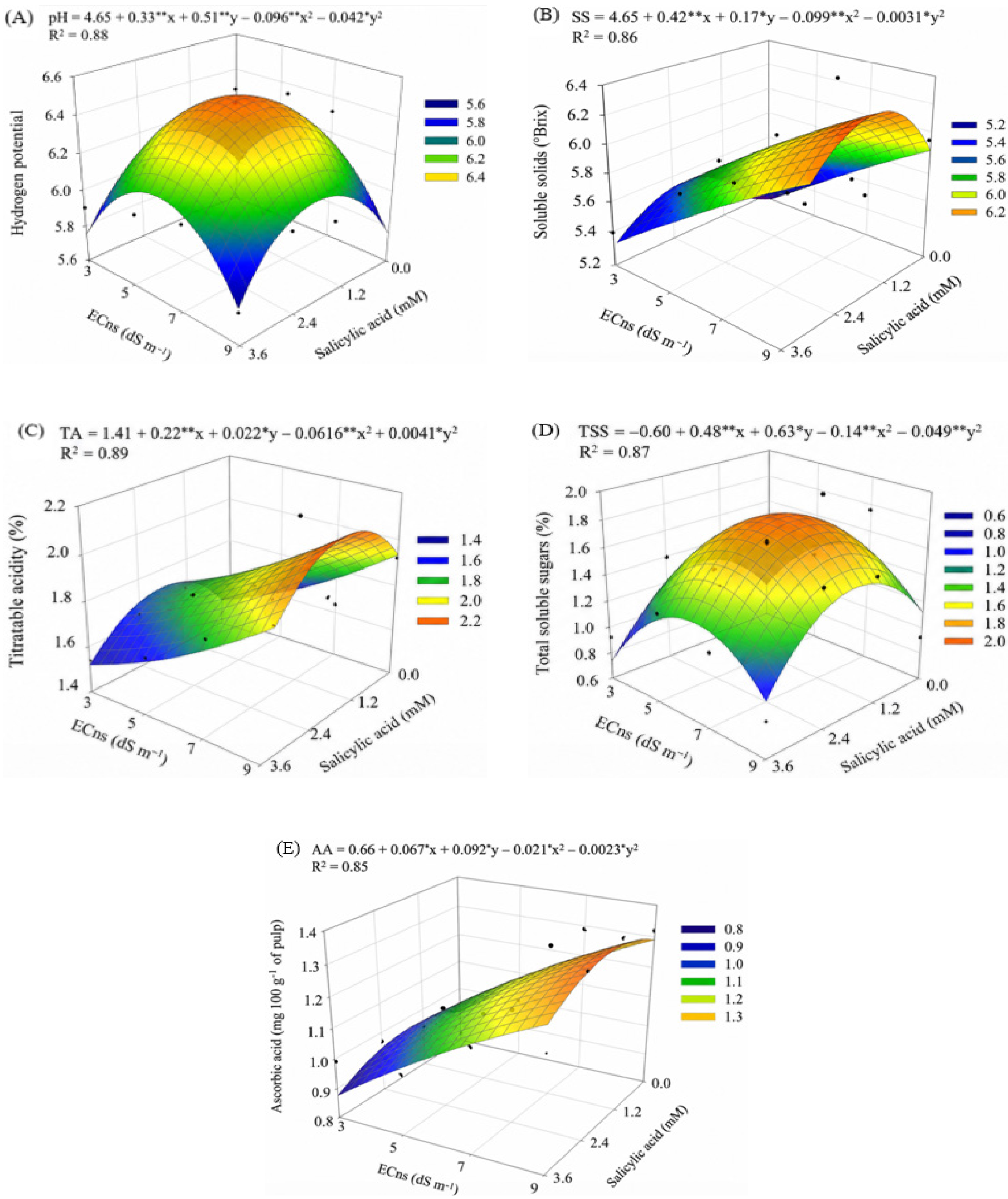
For soluble solids (Figure 5B), plants under ECns of 9.0 dS m^{-1} had the highest value (6.37 ºBrix) with 2.4 mM of SA, while the lowest content (5.13 ºBrix) occurred at 0 mM of SA and 3.0 dS m^{-1}. This variable is important for fresh products because it correlates with sugars and organic acids. The increase in sugars can act on cellular osmotic adjustment. Similar results were observed by Oliveira *et al*. (2022), who found higher levels of soluble solids (6.63 ºBrix) in melon under 5.4 dS m^{-1} and 2.2 mM of salicylic acid.

Table 4 - Summary of the analysis of variance for hydrogen potential (pH), soluble solids (SS), titratable acidity (TA), total soluble sugars (TSS), and ascorbic acid (AA) of okra cv. Canindé cultivated under saline nutrient solution (ECns) and salicylic acid (SA) concentrations in a hydroponic system

Sources of Variation	DF	Mean squares				
		pH	SS	TA	TSS	AA
Saline nutrient solution (ECns)	3	0.086950**	0.063075**	0.090924*	0.820819**	0.280867**
Linear regression	1	0.205335**	0.020535**	0.235000**	0.210634**	0.164327**
Quadratic regression	1	0.045633**	0.147408**	0.235000^{ns}	0.454352**	0.224133**
Residual 1	6	0.000548	0.000367	0.015081	0.000002	0.000002
Salicylic acid (SA)	3	0.220517**	0.858075**	0.159791**	0.456802**	0.016717**
Linear regression	1	0.002802^{ns}	1.224082**	0.000700^{ns}	0.250260**	0.027735**
Quadratic regression	1	0.360533**	0.980408**	0.379852^{ns}	0.977552**	0.020008**
Interaction (ECns × SA)	9	0.319500**	0.572519**	0.128941**	0.356163**	0.067039**
Residual 2	26	0.000661	0.000264	0.007387	0.000002	0.000002
CV 1(%)		0.39	0.33	6.80	0.11	0.13
CV 2(%)		0.43	0.28	4.76	0.11	0.13

DF - degrees of freedom; CV (%) - coefficient of variation; **significant at 0.01 probability level; *significant at 0.05 probability level; ns not significant

Figure 5 - Hydrogen potential – pH (A), soluble solids – SS (B), titratable acidity – TA (C), total soluble sugars – TSS (D), and ascorbic acid – AA (E) in fruits of okra cv. Canindé, as a function of the interaction between saline levels of nutrient solution – ECns and salicylic acid concentrations in hydroponic cultivation



X and Y - salicylic acid concentration - SA and Electrical conductivity of the nutrient solution - ECns, respectively; *, ** - Significant at $p \leq 0.05$ and ≤ 0.01 by the F test, respectively

In relation to titratable acidity (Figure 5C), it was observed that plants subjected to ECns of 9.0 dS m^{-1} and salicylic acid concentration of 2.10 mM obtained the highest value (2.14%). On the other hand, the lowest TA of 1.51% was observed in plants cultivated under a SA concentration of 3.6 mM and ECns of 3.0 dS m^{-1}. The decrease in the titratable acidity of okra fruits is due to secondary fermentations that oxidize lactic acid, producing aromatic compounds (Soares *et al*., 2020). Plants subjected to ECns of 6.1 dS m^{-1} and salicylic acid concentration of 1.50 mM obtained the highest value of total soluble sugars, 1.57% (Figure 5D). On the other hand, the lowest TSS content of 0.84% was observed in plants cultivated under SA concentration of 3.6 mM and ECns of 9.0 dS m^{-1}.

Under conditions of higher nutrient solution salinity (9.0 dS m^{-1}), the application of salicylic acid at a concentration of 1.6 mM promoted the highest levels of ascorbic acid (1.36 mg 100 g^{-1} of pulp) (Figure 5E). On the other hand, when the plants were grown in the nutrient solution with lower salinity (3.0 dS m^{-1}), there was a lower AA content (0.88 mg 100 g^{-1} of pulp) at a SA concentration of 3.6 mM. This result reveals that, at a moderate level of electrical conductivity in the nutrient solution, the ascorbic acid contents tend to increase, which increases the acidic flavor of the fruits. This occurs because the effects of salt stress induce oxidative damage, increasing the antioxidant capacity of plants through a higher concentration of ascorbic acid (Xu *et al*., 2008).

CONCLUSIONS

1. Electrical conductivity of the nutrient solution from 3.0 dS m^{-1} compromises the physiological and production performance of okra cv. Canindé in hydroponic cultivation, reducing initial and maximum fluorescence, electron transport rate, biomass accumulation, root volume, as well as the number, mass and size of fruits per plant;
2. Application of salicylic acid at concentrations between 1.6 and 2.4 mM attenuates the effects of salt stress on post-harvest quality attributes, promoting increments in the levels of soluble solids, titratable acidity and ascorbic acid of okra fruits under nutrient solution salinity of up to 9.0 dS m^{-1}.

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DATA AVAILABILITY STATEMENT

The research data is available in the repository (https://dspace.sti.ufcg.edu.br/handle/riufcg/30836).

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