

Article

Salicylic Acid Modulates Okra Tolerance to Salt Stress in Hydroponic System

Allysson Jonhny Torres Mendonça ¹, André Alisson Rodrigues da Silva ¹, Geovani Soares de Lima ^{1,*}, Lauriane Almeida dos Anjos Soares ², Valeska Karolini Nunes Oliveira ¹, Hans Raj Gheyi ¹, Claudivan Feitosa de Lacerda ³, Carlos Alberto Vieira de Azevedo ¹, Vera Lúcia Antunes de Lima ¹ and Pedro Dantas Fernandes ¹

¹ Academic Unit of Agricultural Engineering, Federal University of Campina Grande, Campina Grande 58430-380, PB, Brazil

² Academic Unit of Agrarian Sciences, Federal University of Campina Grande, Pombal 58840-000, PB, Brazil

³ Department of Agricultural Engineering, Federal University of Ceará, Fortaleza 60455-760, CE, Brazil

* Correspondence: geovani.soares@professor.ufcg.edu.br; Tel.: +55-83-99945-9864

Abstract: Salinity is one of the most devastating abiotic stresses that limit plant growth and yield, especially in arid and semi-arid regions. The objective of this study was to evaluate the effect of foliar application of salicylic acid in mitigating the effects of salt stress on okra cultivation in a hydroponic system. The study was conducted in a greenhouse, consisting of two experiments. A completely randomized design was adopted in a split-plot scheme, with four levels of electrical conductivity of the nutrient solution—EC (2.1; 3.6; 5.1, and 6.6 dS m⁻¹) considered the plots and four salicylic acid concentrations—SA (0, 1.2; 2.4, and 3.6 mM), the subplots, with four replications. The second experiment differed from the first only by the increase in the EC levels (3.0, 5.0, 7.0, and 9.0 dS m⁻¹). An increase in the electrical conductivity of the nutrient solution negatively affected the physiology and production components of okra. However, foliar application of salicylic acid at concentrations between 1.2 and 2.3 mM reduced the harmful effects of salt stress. The salinity threshold for hydroponic cultivation of okra was 2.54 dS m⁻¹, with a reduction of 7.98% per unit increment in EC above this level.

Keywords: *Abelmoschus esculentus*; saline water; soilless cultivation; phytohormone



Citation: Torres Mendonça, A.J.; Silva, A.A.R.d.; Lima, G.S.d.; Soares, L.A.d.A.; Nunes Oliveira, V.K.; Gheyi, H.R.; Lacerda, C.F.d.; Azevedo, C.A.V.d.; Lima, V.L.A.d.; Fernandes, P.D. Salicylic Acid Modulates Okra Tolerance to Salt Stress in Hydroponic System. *Agriculture* **2022**, *12*, 1687. <https://doi.org/10.3390/agriculture12101687>

Academic Editor: Jie He

Received: 20 September 2022

Accepted: 11 October 2022

Published: 13 October 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The semi-arid region of northeastern Brazil has low rainfall and high evaporation rates, naturally contributing to a water deficit and an increase in salt concentrations of the water sources, which limits crop growth and development [1,2]. Excess salts in water and/or soil compromise crop yield due to the reduction in osmotic and water potentials, which consequently reduces water availability, absorption, and transport of nutrients to the shoot [3].

Salinity alters the metabolic and biochemical activities of plants, negatively affecting their production due to the decrease in stomatal conductance and photosynthesis rate, inhibition of protein synthesis and enzymatic activities, and intensification of chlorophyll degradation [4]. Salt stress can also modify the transport of electrons and alter the activity of photosystem II, which is responsible for oxidizing water molecules in order to produce electrons [5].

Globally, irrigation consumes approximately 70% of fresh water annually, mainly from surface reservoirs, rivers, and groundwater [6]. However, the use of hydroponic systems can reduce water consumption and the environmental impacts caused by irrigation. Hydroponic systems are important technologies for better water use efficiency and increased yield and quality of cultivation, especially of vegetables [7]. In addition, it reduces the effects of salinity on plants due to the absence of the matric potential [8].

Hydroponic systems can be classified as static or dynamic (in terms of circulation of the nutrient solution) and as open or closed (in terms of return of the solution to the reservoir) [9]. The NFT (laminar flow of nutrients) hydroponic system is a closed system with recirculation of the nutrient solution, being the most used in the cultivation of fast-growing vegetables [10,11], such as okra.

Given the growing need to use saline water, studies that enable its use have become important. In addition, substances that can be employed to reduce the deleterious effects of salinity, such as salicylic acid (SA), have emerged as a promising alternative for the utilization of these water sources [12].

Salicylic acid is a phenolic compound that plays an important role in the signaling of biotic and abiotic stresses [13,14]. Under conditions of salt stress, SA acts in several physiological and biochemical processes, contributing to the increase of photosynthetic activity, through improvements in antioxidant and metabolic defense, avoiding lipid peroxidation caused by reactive oxygen species (ROS) [15]. Salicylic acid (varying from 0 to 3.6 mM) is also involved in plant growth and physiological processes such as stomatal opening and closure, ion absorption, photosynthesis, and transpiration [16].

In recent years, studies have reported that foliar application of salicylic acid can mitigate the harmful effects caused by salt stress on several vegetables, such as bell pepper [17], tomato [18], eggplant [19], melon [20], coriander [21], and basil [22]. Okra (*Abelmoschus esculentus* L.) is an annual vegetable belonging to the Malvaceae family, native to Africa [23]. Okra is an important vegetable in the human diet, being a source of carbohydrates, proteins, fats, minerals, and vitamins [24]. Its cultivation is common in the semi-arid region of northeastern Brazil because it is a rustic crop and tolerant to high temperatures [25], being a good income alternative for farmers.

This study is based on the hypothesis that foliar application of salicylic acid induces salt tolerance in okra cultivated in a hydroponic system by reducing cell membrane damage and stomatal regulation, increasing photosynthetic activity, which will reflect in the production and productivity gains of okra. In this context, the objective of this study was to evaluate the effect of foliar application of salicylic acid concentrations in mitigating the effects of salt stress on okra cultivation in an NFT (Nutrient Film Technique) hydroponic system.

2. Materials and Methods

2.1. Location of the Experiment

The study consisted of two experiments: the first was conducted during the period from October to December 2021 (season of higher temperatures), and the second between January and March 2022 (season of relatively milder temperatures) in a greenhouse belonging to the Center for Sciences and Agrifood Technology (CCTA) of the Federal University of Campina Grande (UFCG), in Pombal, Paraíba, Brazil, located at the geographic coordinates 6°46'13" S, 37°48'6" W and average altitude of 184 m. The data of temperature (maximum and minimum) and average relative air humidity of the experiment site are presented in Figure 1.

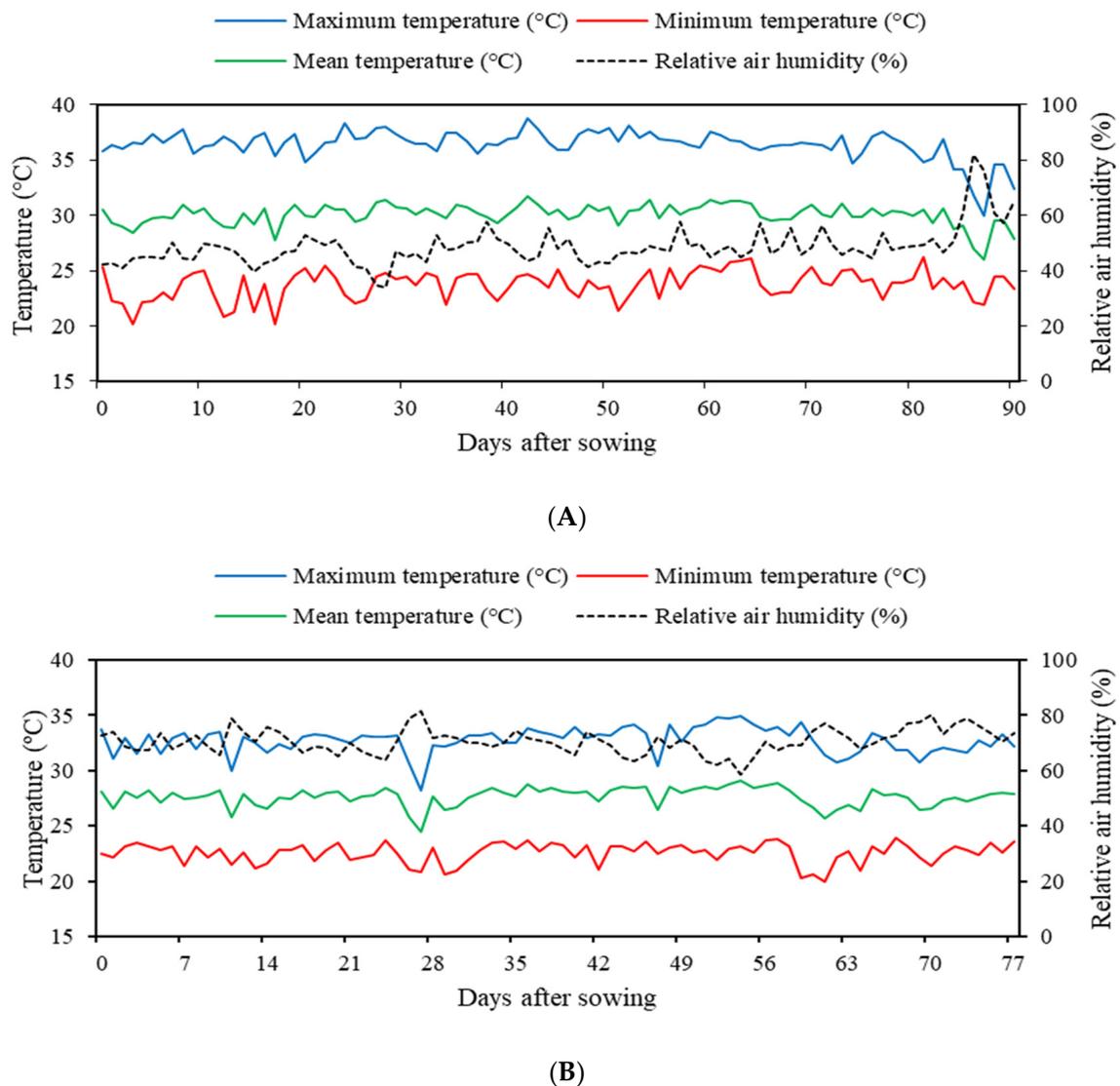


Figure 1. Maximum, minimum, and mean temperature and mean relative air humidity observed in the internal area of the greenhouse during the first (A) and second (B) experiment.

2.2. Treatments and Experimental Design

2.2.1. Experiment I

A completely randomized design was adopted in a split-plot scheme, with four levels of electrical conductivity of the nutrient solution—EC (2.1—control, 3.6, 5.1, and 6.6 dS m^{-1}) considered the plots and four salicylic acid concentrations—SA (0—control, 1.2, 2.4, and 3.6 mM), the subplots, with four replications and two plants per plot. Salicylic acid concentrations were applied by foliar spraying.

2.2.2. Experiment II

The second experiment differed from the first only by the increase in EC levels (3.0—control, 5.0, 7.0, and 9.0 dS m^{-1}). The concentrations of salicylic acid used here were based on a study conducted with melon [20], while the salinity levels of the nutrient solution were adapted from the study conducted by [23] with okra cv. ‘Santa Cruz’.

2.3. Description of the Experiments

The hydroponic system used was Nutrient Film Technique—NFT type, made with polyvinyl chloride (PVC) pipes 100 mm in diameter and six meters long, spaced 0.40 m

apart. In the channels, the spacing was 0.50 m between plants and 1.0 m between treatments (subsystems), and the planting cells had a diameter of 54.17 mm. The channels were supported on sawhorses with 0.60 m height and a 4% slope for the nutrient solution to flow. At the lowest point of each bench of the hydroponic system, a 150 L polyethylene reservoir was positioned to collect and conduct the nutrient solution back to the channels. The nutrient solution was injected into the cultivation channels by a 35 W-pump with a flow rate of 3 L min⁻¹. The circulation of the nutrient solution was programmed with a timer, with an intermittent flow of 15 min every hour during the day and every 30 min at night.

The nutrient solution was prepared according to the recommendation of Hoagland [26], using local-supply water with electrical conductivity of 0.3 dS m⁻¹, resulting in the lowest level (control) of EC (2.1 dS m⁻¹). The electrical conductivity levels of the nutrient solution were verified using a benchtop conductivity meter (MB11, MS Techonopon[®], Piracicaba, Brazil). The chemical composition and quantity of fertilizers used in the preparation of the nutrient solution are shown in Table 1.

Table 1. Chemical composition of nutrient solution of Hoagland and Arnon (1950), used in the hydroponic cultivation of okra.

Element	Nutrient Solution mg L ⁻¹	Fertilizer	Nutrient Solution g L ⁻¹
N	210	KH ₂ PO ₄	136.09
P	31	KNO ₃	101.10
K	234	Ca(NO ₃) ₂ ·4H ₂ O	236.15
Ca	200	MgSO ₄ ·7H ₂ O	246.49
Mg	48	H ₃ BO ₃	3.10
S	64	MnSO ₄ ·4H ₂ O	1.70
B	0.5	ZnSO ₄ ·7H ₂ O	0.22
Mn	0.5	CuSO ₄ ·5H ₂ O	0.75
Zn	0.05	(NH ₄) ₆ Mo ₇ O ₂₄ ·4H ₂ O	1.25
Cu	0.02	FeSO ₄	13.9
Mo	0.01	EDTA—Na	13.9
Fe	5		
Na	1.2		
Cl	0.65		

Seeds of the hybrid okra ‘Canindé’ from Isla[®] (Porto Alegre, Brazil) were used in this study. This cultivar has a cycle of approximately 80 days, plants of tall stature, and is highly productive, with excellent adaptability in different regions. The fruits have five ridges and excellent postharvest quality, with lengths between 10 and 15 cm and diameters ranging from 18 to 20 mm. In addition, ‘Canindé’ okra is resistant to the Yellow Vein Mosaic Virus (YVMV) [27].

Sowing was carried out in 50 mL polyethylene containers containing vegetable sponges of plants of genera *Luffa* (*Luffa aegytiaca*), arranged in trays. Before sowing, the sponges were sanitized using 2.5% sodium hypochlorite, washed, and dried outdoors. Until the emergence of the first true leaves (on average, ten days after sowing), a half-strength nutrient solution was used. After the emergence of the first true leaves, the vegetable sponge was removed, the seedlings were inserted in the hydroponic profiles, and nutrient solution with full strength began to be used.

The saline solutions used in the cultivation were obtained by adding sodium (NaCl), calcium (CaCl₂·2H₂O), and magnesium chloride (MgCl₂·6H₂O) salts to the nutrient solution prepared in water from the supply system of the municipality of Pombal, Paraíba, Brazil, maintaining an equivalent proportion of 7:2:1, respectively. This is the proportion of Na, Ca, and Mg commonly found in the waters used for irrigation in the semi-arid region of northeastern Brazil [28].

The complete replacement of the nutrient solution occurred every eight days; however, electrical conductivity and pH were monitored daily, and whenever necessary, the solution

was adjusted by adding either local-supply water with EC of 0.3 dS m^{-1} or nutrient solution as needed, always maintaining the EC according to the established treatments. The pH was maintained between 5.5 and 6.5 by adding 0.1 M KOH or HCl. Plants were cultivated using vertical support with nylon strings (Figure 2).



Figure 2. Cultivation of okra in Nutrient Film Technique—NFT hydroponic system at different stages of development.

Salicylic acid concentrations were obtained by dissolution in 30% ethyl alcohol, prepared before each application event. The first application was performed 48 h after transplanting the seedlings and 72 h before the saline nutrient solution was applied, between 17:00 and 18:00 h; the other applications were performed at intervals of 10 days, until the beginning of the flowering stage, spraying the abaxial and adaxial sides of the leaves, fully wetting the leaf blades using a sprayer. During SA spraying, a plastic tarpaulin structure was used to avoid drifting onto neighboring plants.

2.4. Variables Analyzed

At 60 days after transplanting (DAT), the relative water content, percentage of intercellular electrolyte leakage, leaf gas exchange, and chlorophyll *a* fluorescence were evaluated. Subsequently, harvest was carried out, and the following production components were obtained: number of fruits per plant, average fruit weight, yield, fruit length, and fruit diameter.

Relative water content (RWC) was determined using the methodology described by [29], while the percentage of intercellular electrolyte leakage (% IEL) was determined using the methodology of [30].

Leaf gas exchanges, represented by stomatal conductance (g_s , $\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$), transpiration (E , $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$), CO_2 assimilation rate (A , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), internal CO_2 concentration (C_i , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), instantaneous water use efficiency (WUE_i , $[(\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}] (A/E)$), and instantaneous carboxylation efficiency (CE_i , $[(\mu\text{mol m}^{-2} \text{ s}^{-1}) (\mu\text{mol mol}^{-1})^{-1}] (A/C_i)$), were measured on the third leaf, counted from the apex of the main branch of the plant, using irradiation of $1200 \mu\text{mol photons m}^{-2} \text{ s}^{-1}$ and airflow of 200 mL min^{-1} , with the portable photosynthesis meter LCPro+ from ADC BioScientific Ltd.a (Hoddesdon, England). Leaf gas exchange measurements were performed between 08:00 and 10:00 h under ambient conditions of temperature and CO_2 concentration.

Chlorophyll fluorescence was evaluated on the third leaf, counted from the apex of the main branch of the plant, at 08:00 h, using an OS5p pulse-modulated fluorimeter from Opti Science, adopting the F_v/F_m protocol to determine the variables: initial fluorescence

(F_0), maximum fluorescence (F_m), variable fluorescence ($F_v = F_m - F_0$) and quantum efficiency of photosystem II (F_v/F_m). This protocol was performed after adaptation of the leaves to the dark for a period of 30 min, using a clip of the device, in order to ensure that all acceptors were oxidized, i.e., with the reaction centers open [31]. Subsequently, the evaluations were carried out under light conditions, using an actinic illumination source with multi-flash saturating pulse coupled to a clip to determine the initial fluorescence before the saturating pulse (F_s), maximum fluorescence after adaptation to saturating light (F_{ms}), electron transport rate (ETR), and the quantum efficiency of photosystem II (Y_{II}).

Okra fruits were harvested when they reached the harvest point, which occurred 4 to 5 days after anthesis. At the harvest, fruits were between 10 and 15 cm in length [32]. In all, five harvests were performed at two-day intervals. The fruits were weighed on a scale with a resolution of 0.01 g. The number of fruits per plant, average fruit weight (g), yield ($t\ ha^{-1}$), average fruit length (cm), and average fruit diameter (mm) were evaluated. The yield was obtained by multiplying the total production per plant (kg per plant) by the number of plants per hectare (considering a planting density of 20,000 plants).

2.5. Salinity Tolerance

The data of total production per plant in both experiments were used to determine the level of tolerance of hydroponic okra plants to salt stress, based on relative yield, using the plateau followed by the linear decrease model proposed by [33]. The model parameters were fitted by minimizing the square of errors with the Microsoft Excel Solver tool, as reported by [34]. Plants were classified according to the level of tolerance, adopting the criterion of reduction in relative yield [35], with four classification levels: T (tolerant; a decrease of 0–20%), MT (moderately tolerant; a decrease of 20–40%), MS (moderately sensitive; a decrease of 40–60%) and S (sensitive; a decrease > 60%). The percentage of loss was based on the total production per plant at a given salinity level, compared to the condition of the lowest EC ($2.1\ dS\ m^{-1}$).

2.6. Statistical Analysis

The collected data were subjected to the distribution normality test (Shapiro–Wilk test) at 0.05 probability level. Subsequently, analysis of variance was performed at a 0.05 probability level, and in the cases of significance, regression analysis was performed using the statistical program SISVAR-ESAL [36]. The choice of model was based on the coefficient of determination. In the case of the significance of the interaction between factors, TableCurve 3D v4.0 software was used to create the response surfaces.

3. Results

3.1. Experiment I

The interaction between the electrical conductivity of the nutrient solution and the concentrations of salicylic acid ($EC \times SA$) did not significantly influence the relative water content and the percentage of intercellular electrolyte leakage. The electrical conductivity of the nutrient solution significantly affected ($p \leq 0.01$) only the relative water content, i.e., no significant effect on leakage of electrolytes in the leaf blade was observed in plants cultivated with EC of up to $6.6\ dS\ m^{-1}$.

The increase in the electrical conductivity of the nutrient solution reduced the relative water content of okra plants (Figure 3) by a 1.98% per unit increase in EC. When comparing the relative water content of plants cultivated with EC of $6.6\ dS\ m^{-1}$ to the relative water content of those subjected to EC of $2.1\ dS\ m^{-1}$, the reduction was 9.3%.

All variables of leaf gas exchange were significantly influenced ($p \leq 0.01$) by the interaction between the electrical conductivity of the nutrient solution and the concentration of salicylic acid ($EC \times SA$); the saline nutrient solution isolated also affected all variables except internal CO_2 concentration and stomatal conductance while no variables were influenced by the application of salicylic acid.

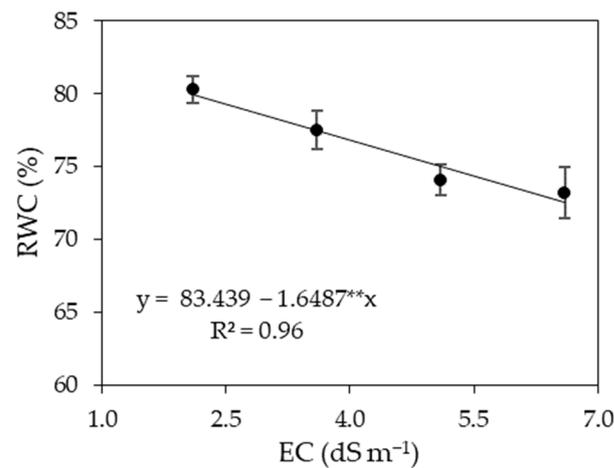


Figure 3. Relative water content—RWC of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution (EC) 60 days after transplanting. ** Significant at $p \leq 0.01$. The vertical lines represent mean \pm standard error ($n = 4$).

The increase in the electrical conductivity of the nutrient solution increased the internal CO_2 concentration, regardless of the salicylic acid concentration (Figure 4A). It was also verified that the application of salicylic acid up to 1.9 mM increased internal CO_2 concentration, whose highest value ($172.73 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) was obtained in plants grown under EC of 6.6 dS m^{-1} and sprayed with SA at the concentration of 1.9 mM, corresponding to an increase of 8.0% ($12.84 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) compared to plants irrigated with the same EC (6.6 dS m^{-1}) and without application of SA (0 mM).

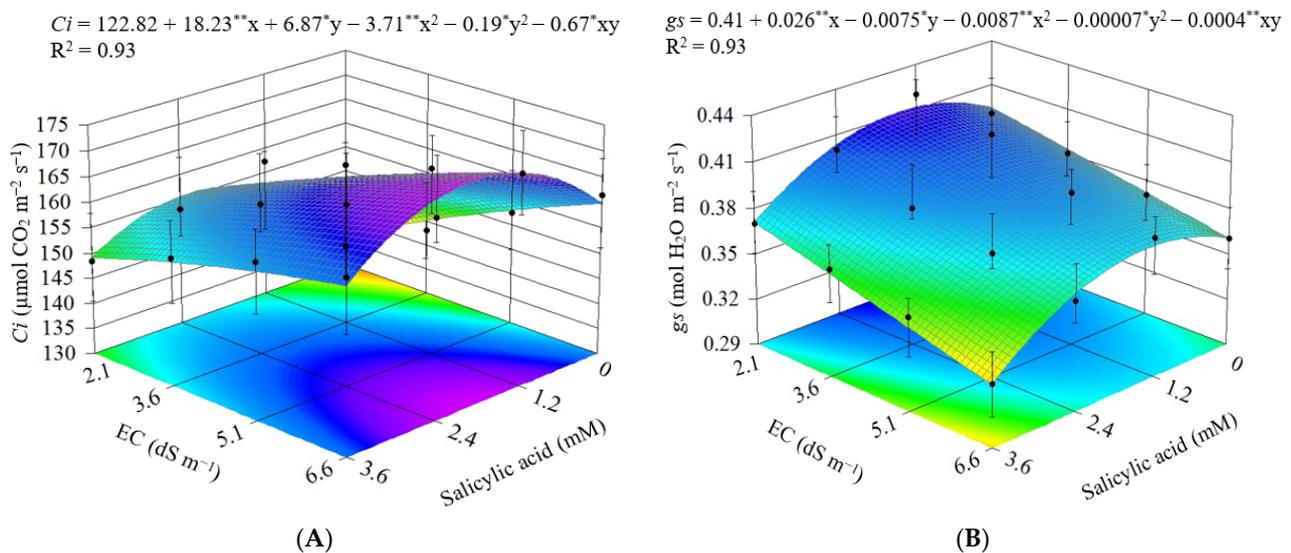


Figure 4. Response surface for internal CO_2 concentration— C_i (A) and stomatal conductance— g_s (B) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the interaction between the electrical conductivity of the nutrient solution (EC) and the concentrations of salicylic acid, 60 days after transplanting. X and Y—concentration of salicylic acid and EC, respectively; * and ** Significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

Foliar application of salicylic acid with concentrations up to 1.4 mM promoted an increase in stomatal conductance (Figure 4B), even when plants were irrigated with the highest salinity level (6.6 dS m^{-1}). The highest value of stomatal conductance ($0.405 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) was obtained in plants irrigated with EC of 3.0 dS m^{-1} and sprayed with SA at the concentration of 1.4 mM, corresponding to an increase of 4.65% ($0.018 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) compared to

plants irrigated with the same salinity level (3.0 dS m^{-1}) and without application of SA (0 mM). However, foliar application of SA at concentrations greater than 1.4 mM intensified the harmful effects of salt stress on stomatal conductance, with the lowest value of stomatal conductance ($0.329 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$) in plants irrigated with EC of 6.6 dS m^{-1} and sprayed with SA at the concentration of 3.6 mM .

The transpiration of okra plants was reduced by the increase in the electrical conductivity of the nutrient solution at all concentrations of salicylic acid (Figure 5A). It was also verified that the increase in SA concentrations above 2.3 mM reduced transpiration, and the lowest value of transpiration ($4.65 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) was recorded in plants grown under EC of 6.6 dS m^{-1} and sprayed with SA at the concentration of 3.6 mM , while the highest value of transpiration ($5.69 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) was obtained in plants subjected to EC of 2.1 dS m^{-1} and sprayed with SA at 2.3 mM .

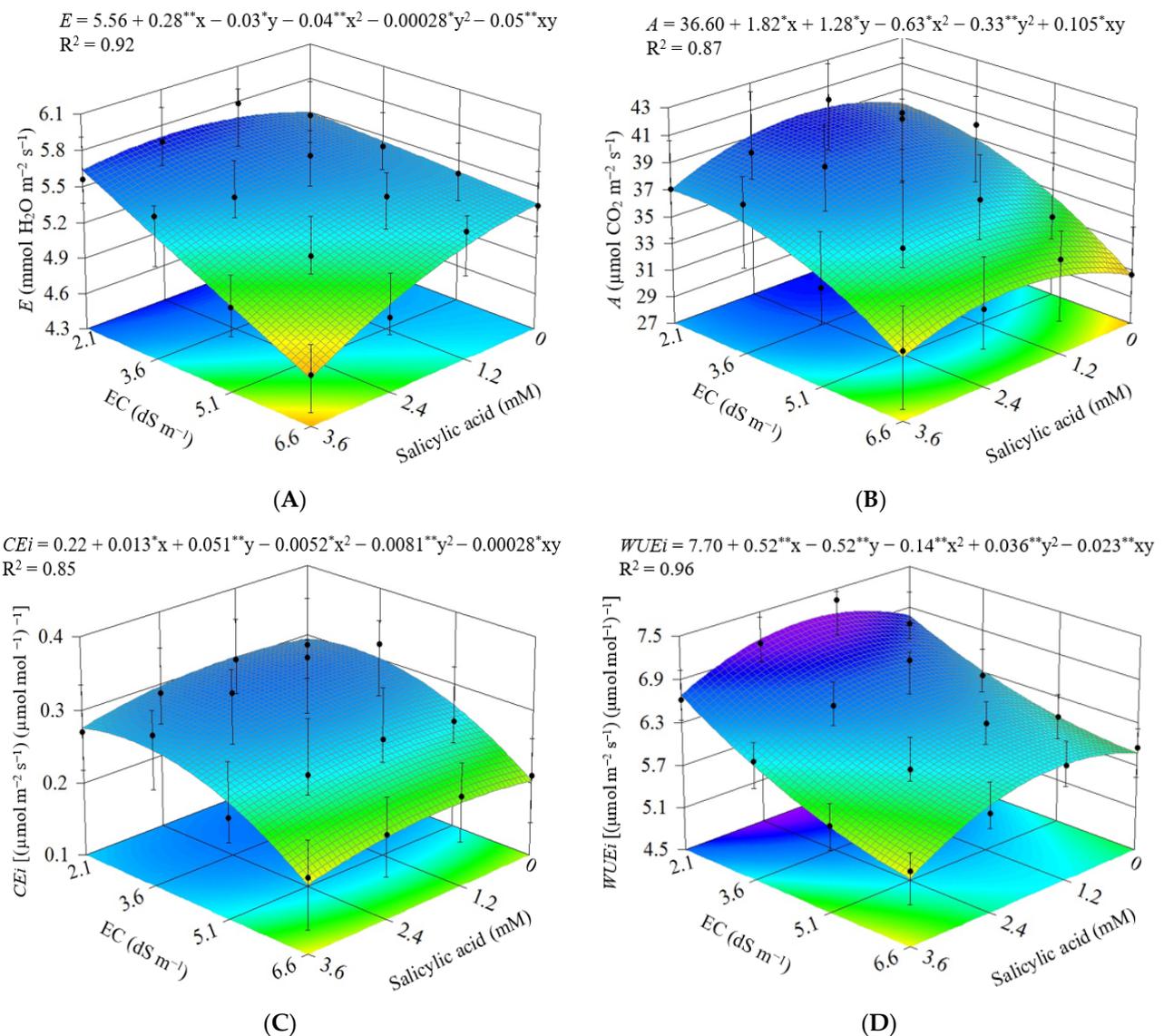


Figure 5. Response surface for transpiration— E (A), CO_2 assimilation rate— A (B), instantaneous carboxylation efficiency— CEi (C), and instantaneous water use efficiency— $WUEi$ (D) of 'Canindé' okra cultivated in a hydroponic system as a function of the interaction between the electrical conductivity of the nutrient solution (EC) and the concentrations of salicylic acid at 60 days after transplanting. X and Y—Concentration of salicylic acid and EC, respectively; * and ** significant at a $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

The CO₂ assimilation rate (Figure 5B) and the instantaneous water use efficiency (Figure 5D) increased with the application of salicylic acid up to the concentration of 1.6 mM, regardless of EC; however, the highest values of CO₂ assimilation rate (39.48 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) and instantaneous water use efficiency (7.16 [$(\mu\text{mol m}^{-2} \text{ s}^{-1}) (\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1})^{-1}$]) were observed in plants grown under EC of 2.3 dS m^{-1} and sprayed with SA at a concentration of 1.6 mM, corresponding to increases of 4.34% in CO₂ assimilation rate and 5.81% in instantaneous water use efficiency compared to plants subjected to the same level of EC (2.3 dS m^{-1}) and without application of SA (0 mM).

Nutrient solution with electrical conductivity above 3.1 dS m^{-1} negatively affected the instantaneous carboxylation efficiency at all salicylic acid concentrations (Figure 5C). However, salicylic acid at the concentration of 1.2 mM increases instantaneous carboxylation efficiency, especially in plants cultivated with EC up to 3.1 dS m^{-1} , recording the highest value of 0.307 [$(\mu\text{mol m}^{-2} \text{ s}^{-1}) (\mu\text{mol mol}^{-1})^{-1}$].

The treatments alone or through interaction (EC \times SA) did not significantly influence the initial fluorescence, maximum fluorescence, variable fluorescence, the quantum efficiency of photosystem II, initial fluorescence before the saturating pulse, and maximum fluorescence after adaptation to saturating light. The quantum efficiency of photosystem II and the electron transport rate of okra were significantly affected ($p \leq 0.05$) by the electrical conductivity of the nutrient solution.

The quantum efficiency of photosystem II of okra plants was reduced by the increase in the electrical conductivity of the nutrient solution above 2.63 dS m^{-1} (Figure 6A). When comparing the plants subjected to EC of 6.6 dS m^{-1} to those cultivated with EC of 2.63 dS m^{-1} , there was a reduction of 20.1% (0.123). On the other hand, the electron transport rate (Figure 6B) was reduced only when plants were subjected to EC above 3.85 dS m^{-1} , with the lowest value of electron transport rate (36.27) recorded in plants cultivated under EC of 6.6 dS m^{-1} . On the other hand, plants grown with an estimated EC of 3.85 dS m^{-1} showed an increase of 7.93% compared to those subjected to an EC of 2.1 dS m^{-1} .

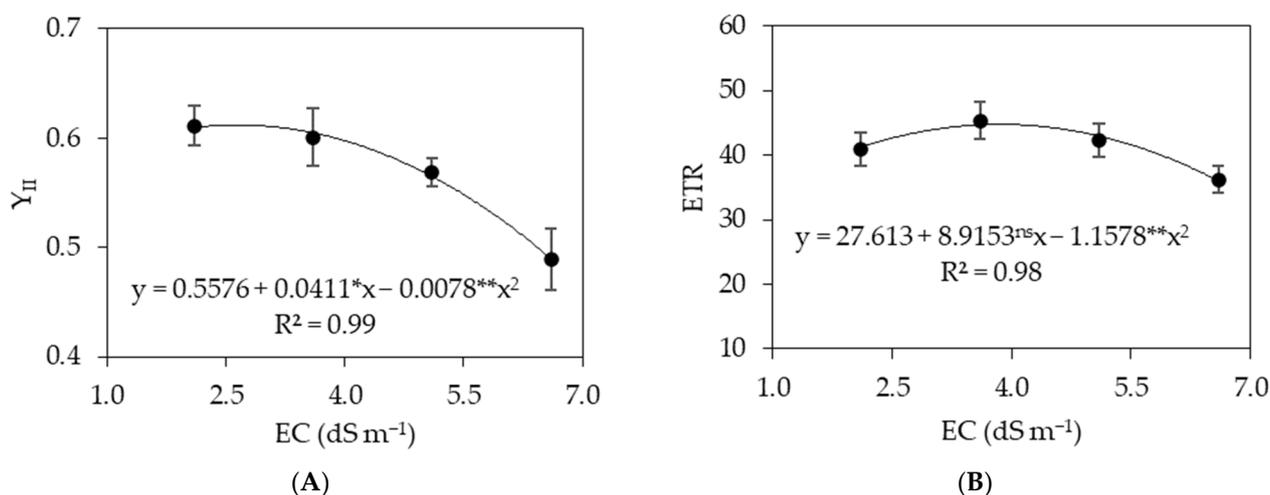


Figure 6. Quantum efficiency of photosystem II— Y_{II} (A) and electron transport rate—ETR (B) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution 60 days after transplanting. * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

There was a significant interaction ($p \leq 0.01$) between the electrical conductivity of the nutrient solution and salicylic acid concentrations only for yield. On the other hand, the electrical conductivities of the nutrient solution significantly influenced all variables of the production components analyzed. Salicylic acid concentrations significantly affected ($p \leq 0.05$) the average weight of okra fruit.

The increase in the electrical conductivity of the nutrient solution caused reductions in the number of fruits per plant and in the average fruit weight (Figure 7A,B), equal to 4.08% and 3.82% per unit increment in EC, respectively, i.e., okra plants grown under an EC of 6.6 had reductions of 20.0% (4.97 fruits per plant) in number of fruits per plant and 18.67% (4.03 g per fruit) in average fruit weight when compared to plants subjected to an EC of 2.1 dS m⁻¹.

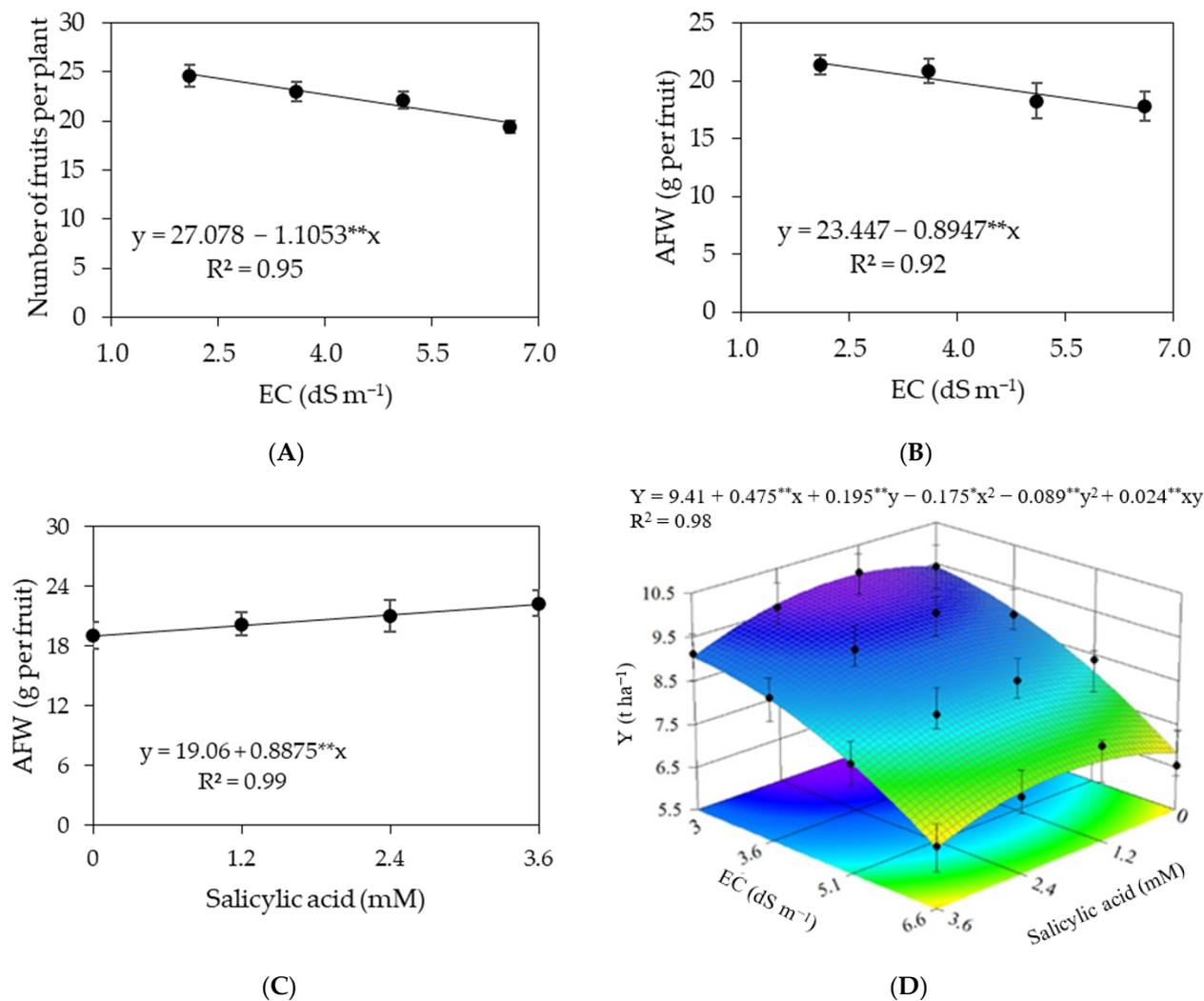


Figure 7. Number of fruits per plant—NFP (A), average fruit weight—AFW (B) of ‘Canindé’ okra as a function of the electrical conductivity of the nutrient solution—EC and the concentrations of salicylic acid (C), and response surface for yield—Y (D) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the interaction between the EC and salicylic acid concentrations. X and Y—concentration of salicylic acid and EC, respectively; * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

Salicylic acid concentrations increased average fruit weight (Figure 7C), with an increase of 4.66% per unit increment of SA concentration. When comparing the average fruit weight of the plants sprayed with a concentration of 3.6 mM of SA to those cultivated under SA of 0 mM, an increase of 16.76% (3.20 g) was noted.

Analysis of the interaction between the factors studied (EC \times SA) on the yield of okra (Figure 7D) showed that plants cultivated with EC of 2.1 dS m⁻¹ and sprayed with SA at the concentration of 1.4 mM stood out with the highest value of yield (9.82 t ha⁻¹), representing an increase of 4.16% (0.39 t ha⁻¹) compared to plants subjected to the same EC (2.1 dS m⁻¹) and without application of salicylic acid (0 mM). However, the increase in

EC reduced yield and its lowest value (6.82 t ha^{-1}) was obtained in plants grown under EC of 6.6 dS m^{-1} and without the application of salicylic acid (0 mM).

The salinity of the nutrient solution negatively affected the length and diameter of okra fruits (Figure 8), with reductions of 1.96% in average fruit length and 1.21% in average fruit diameter per unit increase in EC. When comparing the average fruit length and average fruit diameter of plants cultivated with EC of 6.6 dS m^{-1} to the values of those subjected to EC of 2.1 dS m^{-1} , reductions of 9.22% (1.40 cm) and 5.59% (1.05 mm) were observed in average fruit length and average fruit diameter, respectively.

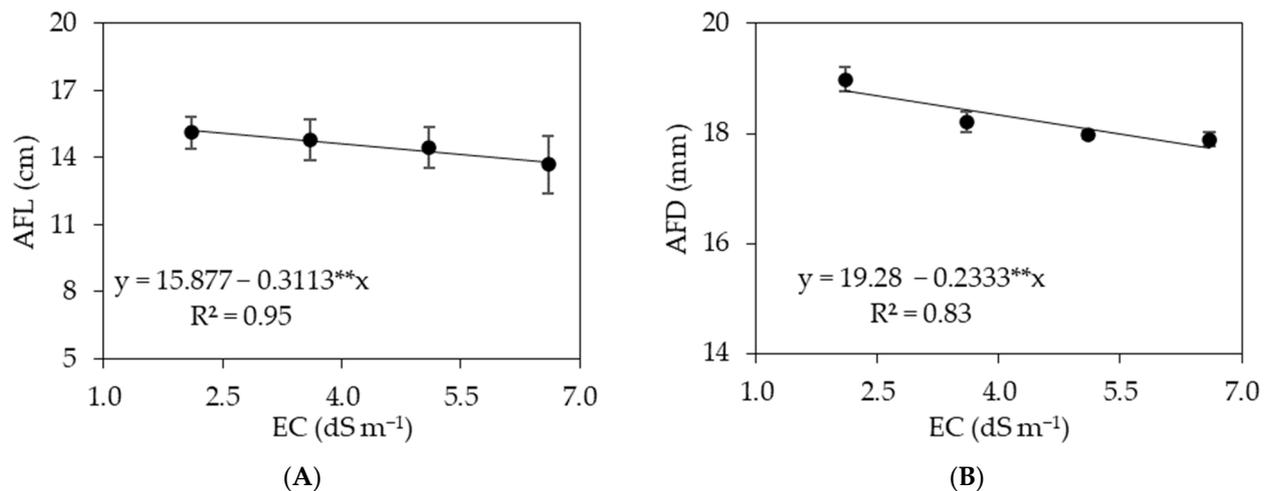


Figure 8. Average fruit length (A) and average fruit diameter (B) of 'Canindé' okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution (EC) in harvest performed in the period from 81 to 91 days after transplanting. ** significant at $p \leq 0.01$. The vertical lines represent mean \pm standard error ($n = 4$).

3.2. Experiment II

The interaction between the electrical conductivity of the nutrient solution and the concentrations of salicylic acid ($\text{EC} \times \text{SA}$) significantly influenced ($p \leq 0.01$) the relative water content and the percentage of intercellular electrolyte leakage of okra.

Foliar application of salicylic acid at the estimated concentration of 0.8 mM promoted an increase in relative water content (Figure 9A), with the highest value (88.8%) obtained in plants cultivated with EC of 3.0 dS m^{-1} . However, it is worth pointing out that the increase in EC reduced relative water content at all concentrations of SA, and the lowest value of relative water content (65.22%) was obtained in plants grown under EC of 9.0 dS m^{-1} and without application of SA (0 mM).

The percentage of intercellular electrolyte leakage in the leaf blade (Figure 9B) was reduced by the application of SA up to a concentration of 1.5 mM , regardless of the EC level. The lowest value of the percentage of intercellular electrolyte leakage (9.43%) was recorded in plants subjected to EC of 3.0 dS m^{-1} and sprayed with SA at the concentration of 1.5 mM . Okra plants subjected to the highest level of EC (9.0 dS m^{-1}) and sprayed with SA at the concentration of 1.5 mM showed a reduction of 14.3% in the percentage of intercellular electrolyte leakage compared to those cultivated with the same EC and without application of SA (0 mM), demonstrating the beneficial effect of salicylic acid on the acclimatization of plants to salt stress.

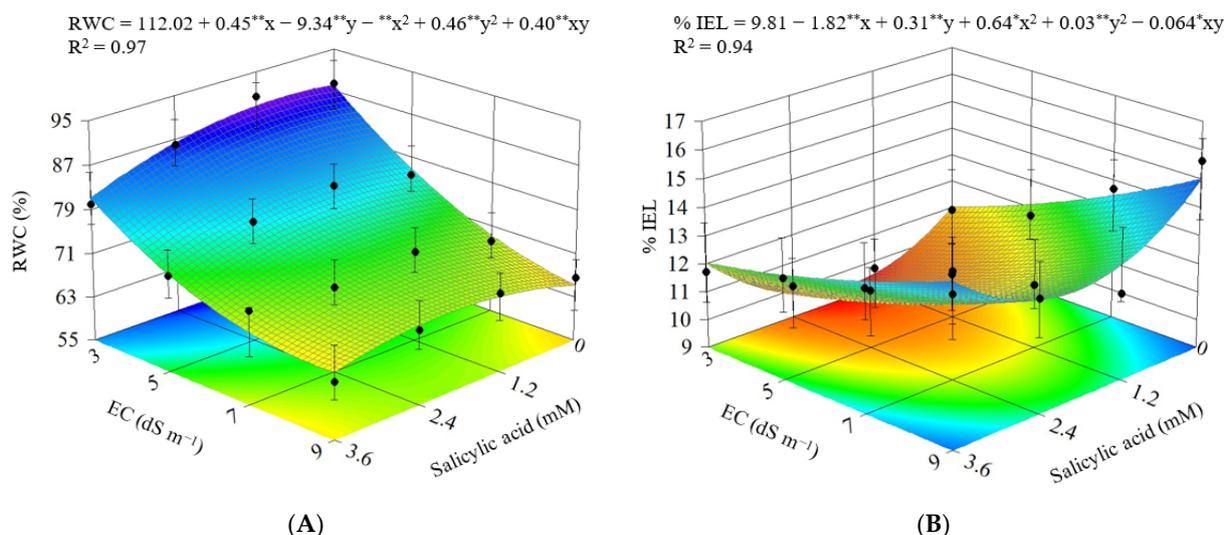


Figure 9. Relative water content—RWC (A) and percentage of intercellular electrolyte leakage—% IEL (B) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the interaction between the electrical conductivity of the nutrient solution (EC) and the concentrations of salicylic acid, 60 days after transplanting. X and Y—Concentration of salicylic acid and EC, respectively; * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error (n = 4).

There was a significant effect of the interaction between the electrical conductivity of the nutrient solution and the concentrations of salicylic acid (EC \times SA) on all leaf gas exchange variables, except for stomatal conductance and instantaneous water use efficiency. However, stomatal conductance and instantaneous water use efficiency were significantly influenced ($p \leq 0.01$) by the levels of electrical conductivity of the nutrient solution. On the other hand, the concentrations of salicylic acid alone had significant effects on stomatal conductance and transpiration.

As observed in Experiment I, the increase in the electrical conductivity of the nutrient solution increased the internal CO₂ concentration (Figure 10) at all salicylic acid concentrations. Okra plants grown under an EC of 9.0 dS m⁻¹ and sprayed with SA at the concentration of 3.6 mM had higher internal CO₂ concentration values (127.6 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$).

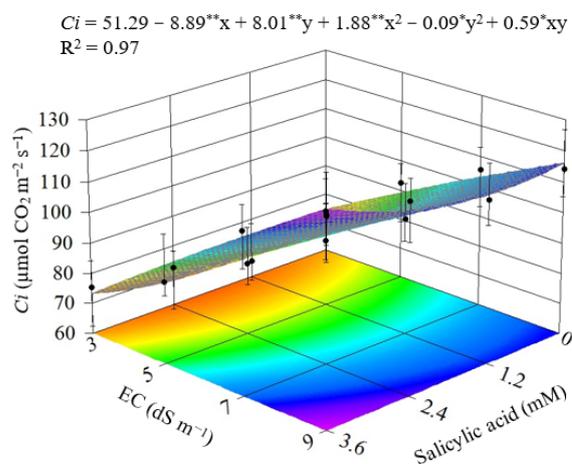


Figure 10. Response surface for internal CO₂ concentration— C_i of ‘Canindé’ okra cultivated in a hydroponic system as a function of the interaction between the electrical conductivity of the nutrient solution (EC) and the concentrations of salicylic acid 60 days after transplanting. X and Y—Concentration of salicylic acid and EC, respectively; * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error (n = 4).

Stomatal conductance was negatively affected by the increase in EC (Figure 11A). When comparing plants grown under an EC of 9.0 dS m^{-1} to those subjected to 3.0 dS m^{-1} , there was a reduction of 39.45% ($0.209 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$). Foliar spraying of salicylic acid up to the estimated concentration of 2.17 mM increased stomatal conductance (Figure 11B). Plants subjected to an SA concentration of 2.17 mM stood out with the highest stomatal conductance ($0.420 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$), corresponding to an increase of 11.4% ($0.043 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$), compared to plants that did not receive SA (0 mM).

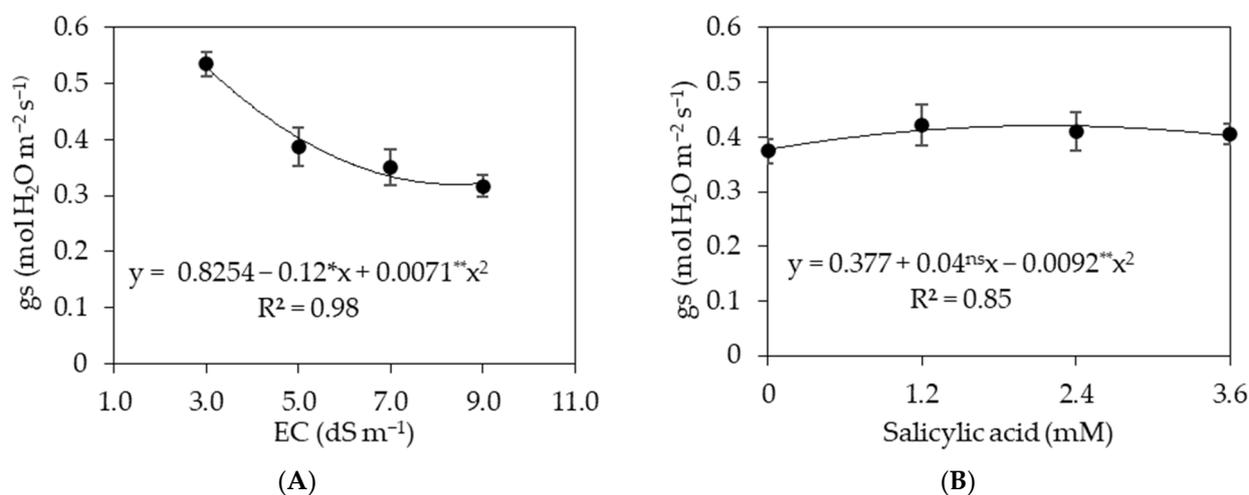


Figure 11. Stomatal conductance— g_s of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution—EC (A) and salicylic acid concentrations (B) 60 days after transplanting. * and ** Significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

Foliar application of salicylic acid up to the concentration of 1.5 mM promoted increments in the transpiration (Figure 12A) and CO_2 assimilation rate (Figure 12B) of okra plants at all levels of EC. However, the highest values of transpiration ($6.55 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) and CO_2 assimilation rate ($45.58 \text{ } \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) were obtained in plants cultivated with EC (3.0 dS m^{-1}) and sprayed with SA at the concentration of 1.5 mM. On the other hand, plants grown under EC of 9.0 dS m^{-1} and without the application of salicylic acid (0 mM) had the lowest values of transpiration ($4.24 \text{ mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) and CO_2 assimilation rate ($35.34 \text{ } \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$).

The instantaneous carboxylation efficiency was favored by the application of salicylic acid up to the concentration of 2.0 mM (Figure 12C). Plants sprayed with a concentration of 2.0 mM of SA and subjected to an EC of 3.0 dS m^{-1} stood out with the highest instantaneous carboxylation efficiency ($0.882 [(\mu\text{mol m}^{-2} \text{ s}^{-1}) (\mu\text{mol mol}^{-1})^{-1}]$), corresponding to an increase of 23.9% compared to plants grown under the same level of EC (3.0 dS m^{-1}) and without the application of SA (0 mM), showing the positive effect of SA up to the concentration of 2.0 mM.

The increase in the electrical conductivity of the nutrient solution reduced the instantaneous water use efficiency of okra (Figure 13) by 5.23% per unit increment in EC, i.e., plants cultivated with an EC of 9.0 dS m^{-1} showed a reduction of 37.45% ($3.73 [(\mu\text{mol m}^{-2} \text{ s}^{-1}) (\mu\text{mol mol}^{-1})^{-1}]$) compared to those subjected to 3.0 dS m^{-1} .

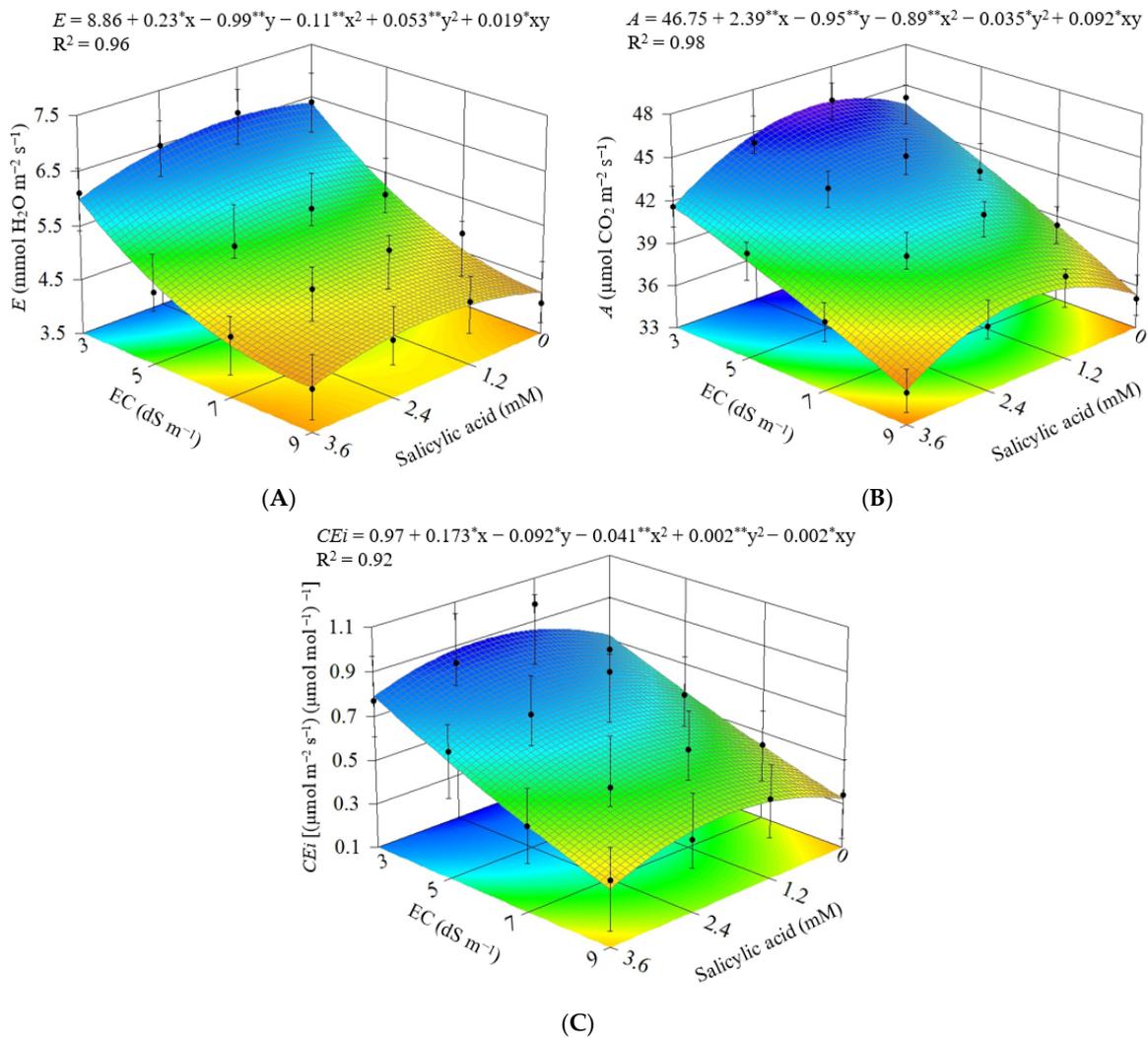


Figure 12. Response surface for transpiration— E (A), CO_2 assimilation rate— A (B), and instantaneous carboxylation efficiency— CEi (C) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the interaction between the electrical conductivity of the nutrient solution (EC) and the concentrations of salicylic acid 60 days after transplanting. X and Y —Concentration of salicylic acid and EC, respectively; * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

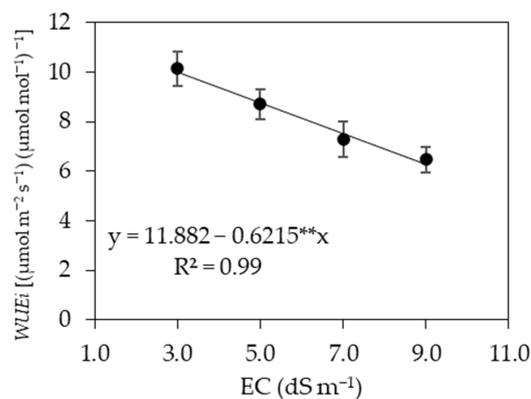


Figure 13. Instantaneous water use efficiency— $WUEi$ of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution (EC) 60 days after transplanting. ** Significant at $p \leq 0.01$. The vertical lines represent mean \pm standard error ($n = 4$).

According to the summary of the analysis of variance, the interaction between the electrical conductivity of the nutrient solution and the concentrations of salicylic acid (EC × SA) significantly affected the initial fluorescence, maximum fluorescence, variable fluorescence, and quantum efficiency of photosystem II of okra plants 60 days after transplanting. The variables of initial fluorescence before the saturating pulse, the quantum efficiency of photosystem II, and the electron transport rate were significantly affected by the electrical conductivity of the nutrient solution 60 days after transplanting.

When analyzing the effect of the interaction between the electrical conductivity of the nutrient solution and the concentrations of salicylic acid on the initial fluorescence of okra plants (Figure 14A), it was verified that the increase in EC promoted an increase in initial fluorescence at all concentrations of salicylic acid. This increase is intensified when SA concentrations above 1.5 mM are used, and the highest value of initial fluorescence (359.51) was observed in plants irrigated with EC 9.0 dS m⁻¹ and sprayed with SA at the concentration of 3.6 mM.

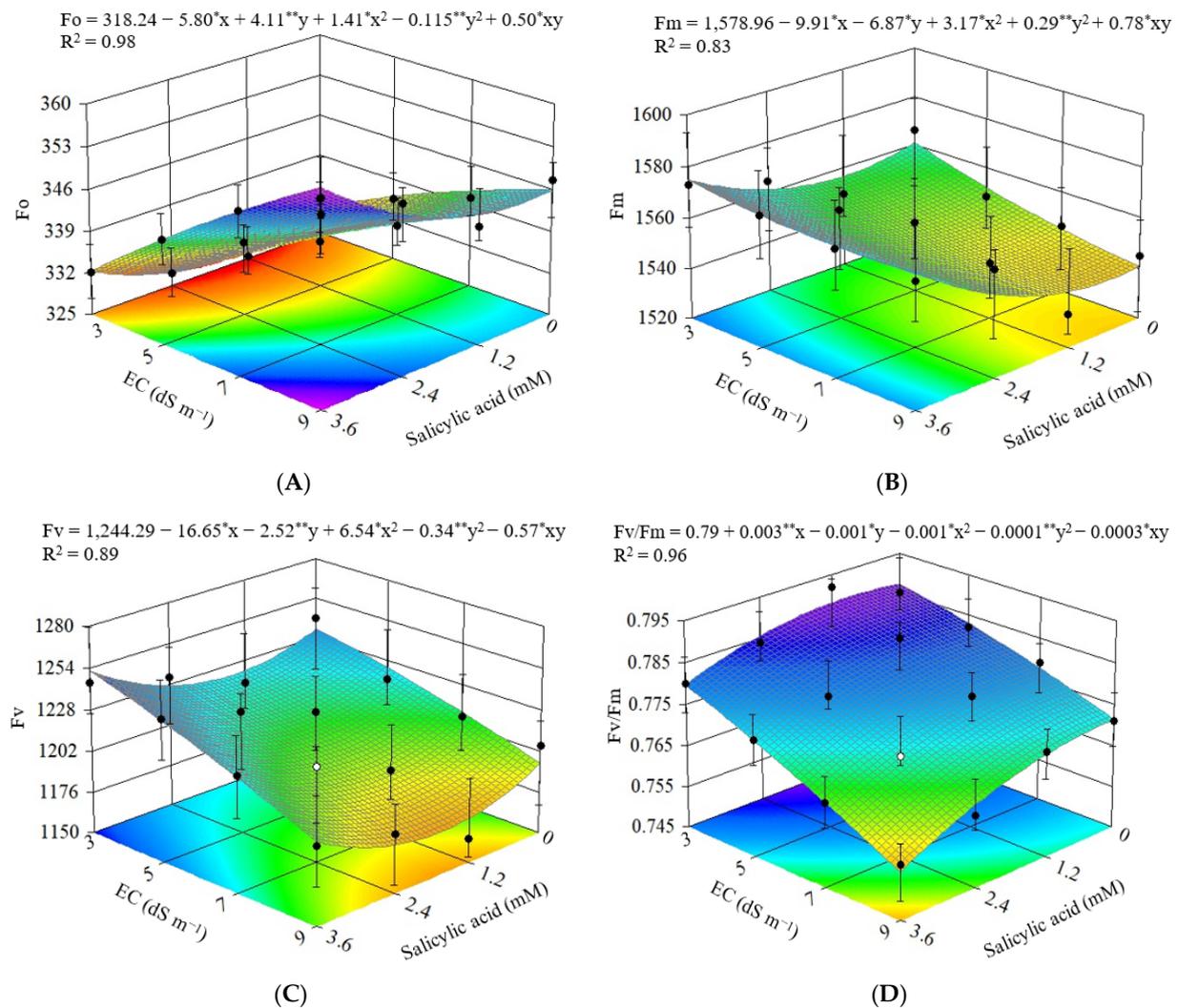


Figure 14. Response surface for initial fluorescence— F_0 (A), maximum fluorescence— F_m (B), variable fluorescence— F_v (C) and the quantum efficiency of photosystem II— F_v/F_m (D) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the interaction between the electrical conductivity of the nutrient solution (EC) and the concentrations of salicylic acid (SA), 60 days after transplanting. X and Y—Concentration of salicylic acid and EC, respectively; * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

Unlike the result observed for F_0 (Figure 14A), the maximum fluorescence (Figure 14B) and variable fluorescence (Figure 14C) were reduced by the increase in the electrical conductivity of the nutrient solution. However, foliar application of SA at the concentration of 3.6 mM promoted increments in maximum fluorescence and variable fluorescence in plants grown under an EC of 3.0 dS m^{-1} , which had the highest values of maximum fluorescence (1574.79) and variable fluorescence (1252.33). In turn, the quantum efficiency of photosystem II in the dark phase (Figure 14D) increased with foliar application of SA at the concentration of 1.2 mM in plants cultivated with an EC of up to 3.6 dS m^{-1} , with the highest value of quantum efficiency of photosystem II (0.787) obtained under an EC of 3.0 dS m^{-1} (Figure 14D).

For the initial fluorescence before the saturating pulse (F_s) (Figure 15A), the increase in EC promoted an increment of 10.03% in plants cultivated with an EC of 9.0 dS m^{-1} compared to those exposed to 3.0 dS m^{-1} . On the other hand, the quantum efficiency of photosystem II in the light phase (Figure 15B) was reduced when nutrient solutions with estimated electrical conductivity above 4.9 dS m^{-1} were used.

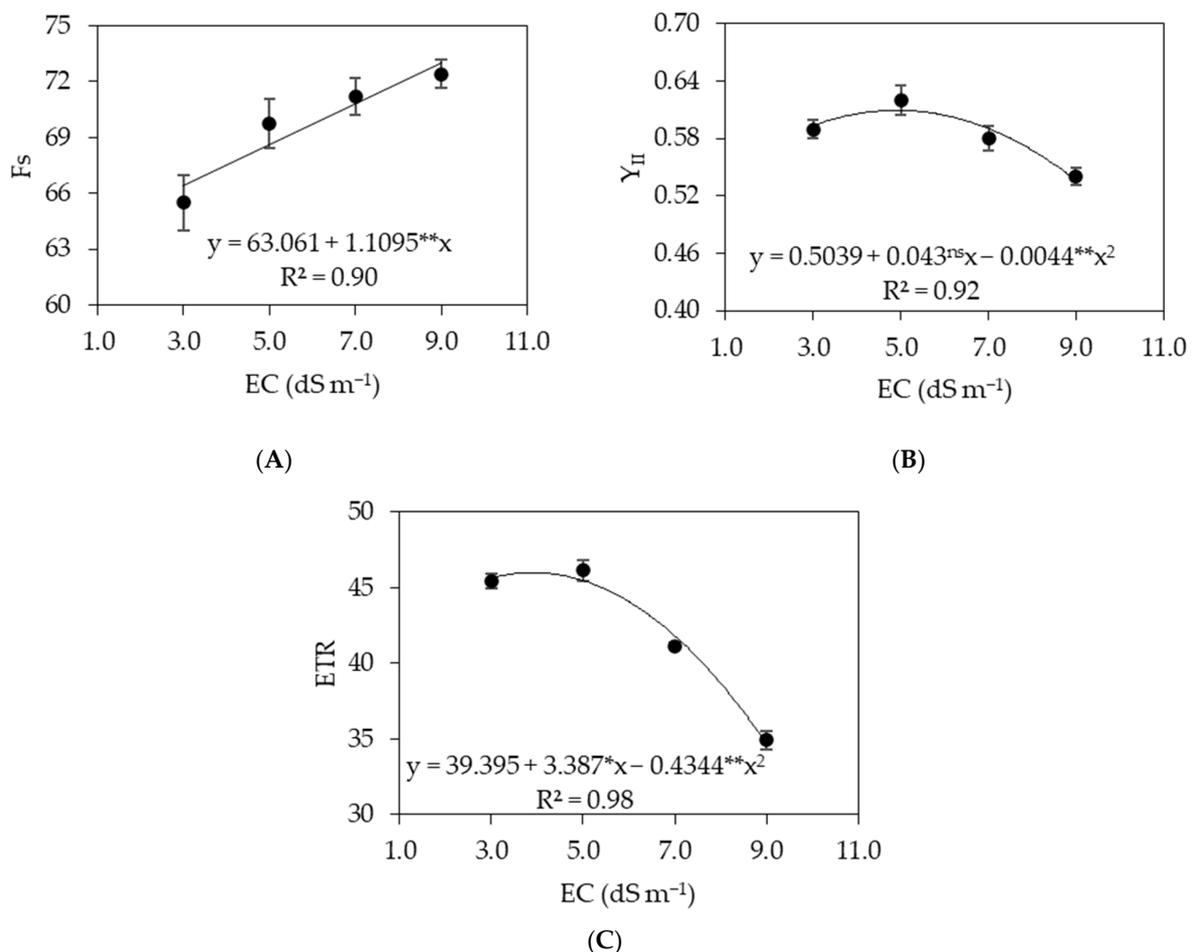


Figure 15. Initial fluorescence before saturating pulse— F_s (A), quantum efficiency of photosystem II in the light phase— Y (B), and electron transport rate—ETR (C) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution (EC) 60 days after transplanting. * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

The use of nutrient solutions with an electrical conductivity of up to 3.9 dS m^{-1} did not cause reductions in the electron transport rate of okra plants (Figure 15C), but there were reductions when an EC above this level was used. It was verified that plants grown

under an EC of 9.0 dS m⁻¹ reached the lowest value of electron transport rate (34.69), that is, a reduction of 24.59% (11.31) compared to plants subjected to an EC of 3.9 dS m⁻¹.

There was a significant interaction ($p \leq 0.01$) between the electrical conductivity of the nutrient solution and the concentrations of salicylic acid only for yield. On the other hand, the electrical conductivities of the nutrient solution significantly influenced ($p \leq 0.01$) all variables of production components, while the concentrations of salicylic acid alone did not affect the production components of okra.

The number of fruits per plant (Figure 16A) and the average fruit weight (Figure 16B) were negatively affected by the increase in the electrical conductivity of the nutrient solution, with reductions of 6.91 in number of fruits per plant and 2.38% in the average fruit weight, respectively, per unit increase in EC, that is, okra plants grown under an EC of 9.0 had reductions of 53.35% (13.45 fruits) in the number of fruits per plant and 15.35% (3.29 g per plant) in the average fruit weight when compared to plants subjected to an EC of 3.0 dS m⁻¹.

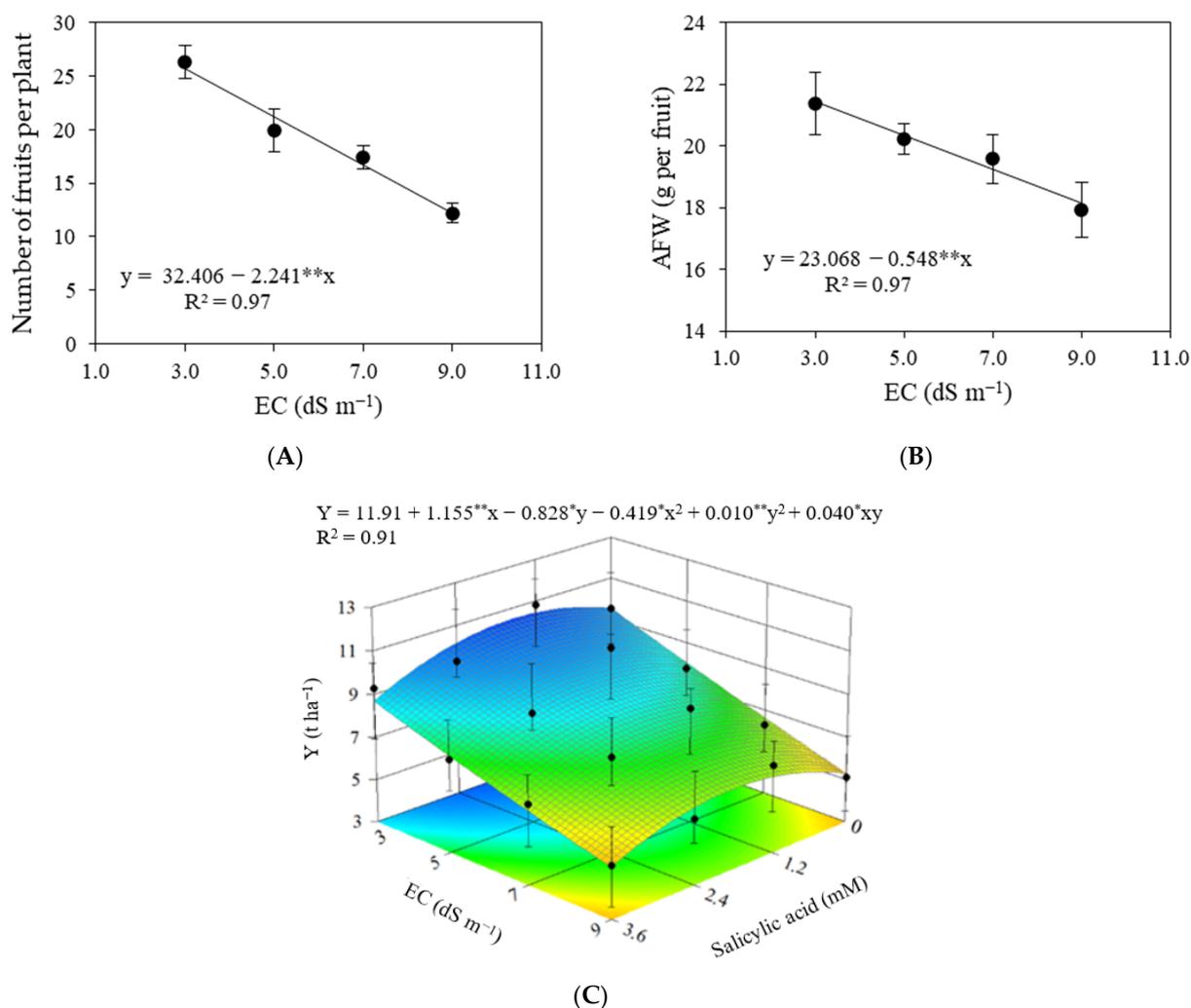


Figure 16. Number of fruits per plant—NFP (A) and average fruit weight—AFW of ‘Canindé’ okra grown in a hydroponic system as a function of the electrical conductivity of the nutrient solution—EC (B), and response surface for yield—Y (C) as a function of the interaction between EC and salicylic acid concentrations. X and Y—Concentration of salicylic acid and EC, respectively; * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error (n = 4).

Foliar application of salicylic acid at the concentration of 1.5 mM associated with an EC of 3.0 dS m⁻¹ promoted the highest value of yield (10.49 t ha⁻¹) in okra plants (Figure 16C),

corresponding to an increase of 10.2% (0.97 t ha^{-1}) compared to plants exposed to the same EC (3.0 dS m^{-1}) and without the application of SA (0 mM). The lowest yield value (5.27 t ha^{-1}) was recorded in plants cultivated with an EC of 9.0 dS m^{-1} and without the application of SA (0 mM).

The increase in the electrical conductivity of the nutrient solution reduced the length and diameter of okra fruits (Figure 17), with reductions of 1.15% in the average fruit diameter per unit increment of EC. When comparing the average fruit length and average fruit diameter of plants cultivated with an EC of 9.0 dS m^{-1} to those of plants subjected to an EC of 3.0 dS m^{-1} , reductions of 19.1% (2.82 cm) and 7.13% (1.31 mm) were observed, respectively.

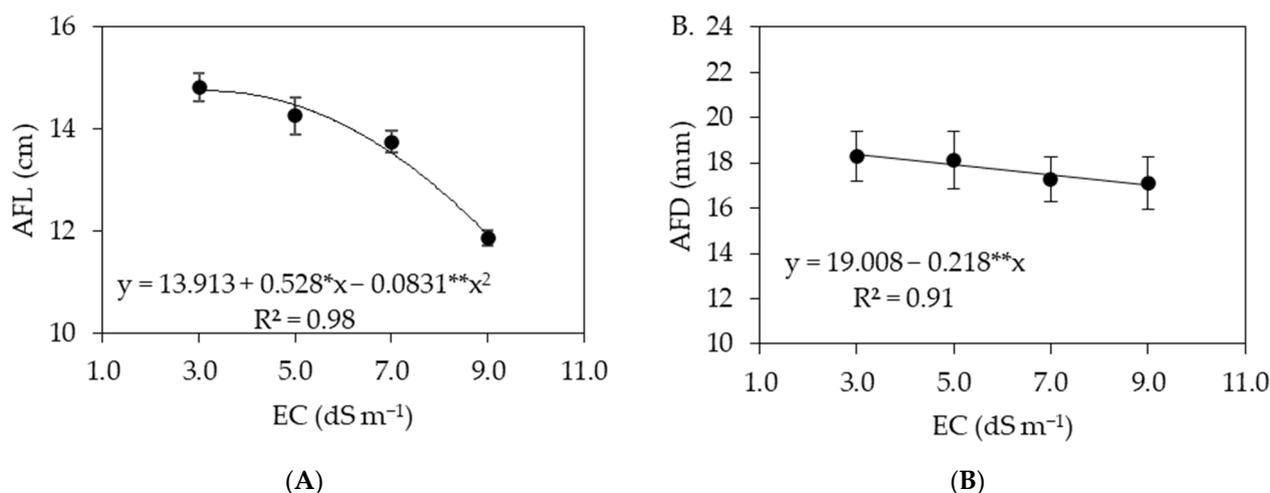


Figure 17. Average fruit length (A) and average fruit diameter (B) of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution (EC) 60 days after transplanting. * and ** significant at $p \leq 0.05$ and ≤ 0.01 , respectively. The vertical lines represent mean \pm standard error ($n = 4$).

4. Discussion

Salinity is one of the main abiotic stresses that affect plant metabolism and limit growth and development, posing serious threats to agriculture and food security [37]. In the present study, it was found that the salinity of the nutrient solution partially compromised the hydroponic cultivation of okra, but the deleterious effects caused by salt stress were reduced by the foliar application of salicylic acid at intermediate concentrations.

Relative water content is an important variable to indicate the water status of plants under different environmental stresses, such as water and salt stresses, because it represents the maximum amount of water that leaves can receive under total turgor [38]. In the present study, it was verified that the increase in salinity of the nutrient solution reduced the relative water content of okra plants (Figures 3 and 7A), and its reduction as a function of salinity may occur due to the osmotic effect, which restricts the absorption of water by plants [39]. Similar results have been reported for different vegetables grown in hydroponic systems, such as melon [20], coriander [21], and tomato [40].

It was found in the first experiment that the use of an EC of up to 6.0 dS m^{-1} did not significantly affect the percentage of intercellular electrolyte leakage, but with the increase in EC levels used in the second experiment, there was a negative effect of salt stress on percentage of intercellular electrolyte leakage; despite that, the observed data are lower than those reported for other vegetables, such as cherry tomatoes [41] and melon [20].

Plants subjected to salt stress generally produce reactive oxygen species (ROS) such as superoxide radicals, hydroxyl radicals, and hydrogen peroxide [42]. The imbalance between the production and elimination of these ROS can cause photooxidative damage to photosystems and peroxidation of the cell membrane [43], promoting an increase in the

percentage of intercellular electrolyte leakage, as observed in the present study (Figure 7B). Nevertheless, this increase did not cause damage to the membrane of okra plants since it is only considered damage when it exceeds 50% of electrolyte leakage [44].

Foliar application of salicylic acid up to the concentration of 1.5 mM was able to reduce the percentage of intercellular electrolyte leakage, even in plants grown under the highest EC level (9.0 dS m^{-1}) (Figure 7B). SA acts in the improvement of the absorption of nutrients, membrane protection, and the increase in photosynthetic activity, besides being able to interact with signaling pathways of ROS and reduce oxidative stress [45,46], consequently reducing the percentage of intercellular electrolyte leakage.

The leaf gas exchange of okra plants was negatively affected by exposure to salt stress. The increase in internal CO_2 concentration (Figures 4A and 10) may be related to the reduction in the activity of the ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO) enzyme and to the degradation of the photosynthetic apparatus in response to leaf tissue senescence, resulting from the stress caused by the excess salts [47,48].

Stomata are the structures responsible for regulating the gas exchange of plants [49]. Okra plants subjected to the highest level of electrical conductivity of the nutrient solution showed greater stomatal closure (Figures 4B and 11A), which occurs as a mechanism of tolerance to reduce the transpiration rate (Figures 5A and 12A) under salt stress conditions and consequently reduce the absorption of water and nutrients [48–50]. However, this reduction in stomatal conductance also reduces the CO_2 assimilation rate (Figures 5B and 12B) and the instantaneous carboxylation efficiency (Figures 5C and 12C). Reductions in gas exchange in okra plants caused by salt stress have also been verified in other studies, such as [51,52].

Foliar application of salicylic acid at concentrations between 1.2 and 2.3 mM promoted an increase in leaf gas exchange, mitigating the deleterious effects of salinity. Salicylic acid is a hormonal signaling molecule synthesized endogenously by plants and has been widely used to mitigate biotic and abiotic stresses [53]. Under conditions of salt stress, SA can contribute to reducing the Na^+ content and increasing K^+ content between the leaves and roots of plants and reduce the production of hydrogen peroxide (H_2O_2) by modulating primary metabolites [46]. SA can increase RuBisCO activity, potassium absorption, and ATP content and maintain an adequate Na^+/K^+ ratio in plants, thus favoring tolerance to salt stress [54].

In a study conducted by [55] evaluating the gas exchange of tomato plants subjected to salicylic acid concentrations (0 to 2.0 mM) applied through the leaves, these authors found a beneficial effect of the application of SA at the concentration of 1.3 mM on gas exchange. When evaluating the soursop crop (*Annona muricata* L.) subjected to salt stress and foliar application of SA concentrations (0 to 3.6 mM), [39] verified that foliar application of SA at concentrations between 1.2 and 1.6 mM mitigated the effects of salt stress on stomatal conductance, CO_2 assimilation rate, transpiration, and instantaneous carboxylation efficiency. In addition, it reduced electrolyte leakage and increased the growth of the plants even when exposed to irrigation water electrical conductivity of 4.0 dS m^{-1} .

The mechanism of action of SA is not yet well understood, mainly because it may differ from species to species, besides varying according to the environmental conditions and concentrations applied [56]. Our results show that at concentrations of SA greater than 2.3 mM, the harmful effects of salt stress were intensified. According to [57], high concentrations of salicylic acid can cause high levels of oxidative stress, leading to reduced tolerance to the stress.

The levels of electrical conductivity of the nutrient solution analyzed in the first experiment (EC of 2.1, 3.6, 5.1, and 6.6 dS m^{-1}) did not significantly affect the chlorophyll a fluorescence variables (F_0 , F_m , F_v , and F_v/F_m), as also observed in electrolyte leakage. However, with the increase of EC levels in the second experiment (EC of 3.0, 5.0, 7.0, and 9.0 dS m^{-1}), there was an increase in the initial fluorescence (F_0), indicating damage to the light-harvesting complex of photosystem II of okra plants. According to [58], this damage occurs due to the decrease in the energy transfer from the light-harvesting system

to the photosystem reaction center. Maximum fluorescence and variable fluorescence were reduced by the increase in the electrical conductivity of the nutrient solution at all concentrations of SA. The reduction in F_m may be an indication that there was low efficiency in the quinone photoreduction and electron flow between the photosystems, which results in low PSII activity in the thylakoid membrane, directly influencing the electron flow between the photosystems [59,60]. In addition, the reduction of variable fluorescence may indicate that the photosynthetic apparatus was damaged by salt stress, compromising the photosystem II, with negative effects on the photosynthetic process [21].

The higher maximum fluorescence (F_m) and variable fluorescence (F_v) observed in plants grown under the lowest EC contributed to improving the quantum efficiency of photosystem II in the dark phase (F_v/F_m). Several authors consider F_v/F_m values between 0.75 and 0.85 as normal in non-stressed plants [61–63]. Thus, the results reveal that, regardless of the concentration of salicylic acid, the quantum efficiency of photosystem II was not compromised by the salinity of the nutrient solution, as the values of the quantum efficiency of photosystem II ranged from 0.76 to 0.79, i.e., they were higher than 0.75.

The reductions in the quantum efficiency of photosystem II in the light phase (Y_{II}) (Figures 6A and 13B) due to the increase in the electrical conductivity of the nutrient solution observed in the present study indicate a decrease in photosynthetic activity, which corroborates the reductions observed in the CO_2 assimilation rate (Figures 5B and 12B) of plants subjected to the highest levels of EC. Photosynthetic performance depends on the electron transport rate [64], which was also compromised by salt stress.

The results of the present study reveal that the increase in the electrical conductivity of the nutrient solution negatively affected the production components and yield of okra, verified by the reductions observed in the number of fruits per plant, average fruit weight, fruit length, fruit diameter, and yield. These results are a consequence of the high salinity of the nutrient solution, which can cause a water deficit by reducing the osmotic potential and the toxicity of specific ions such as Cl^- and Na^+ [8]. Salt stress reduces the activity of ions in solution and alters the processes of absorption, transport, assimilation, and distribution of nutrients in the plant, consequently leading to low yield [65]. Reductions in production components due to salt stress in hydroponic cultivation have also been observed in other studies with okra [66], cauliflower [67], 'biquinho' pepper [34], and zucchini [68].

Despite the reduction in production components, it was observed in the present study that foliar application of salicylic acid at concentrations between 1.4 and 1.5 mM promoted an increase in okra yield, especially in plants cultivated under EC of 3.0 dS m^{-1} . The induction of defense mechanisms, which strengthens stress tolerance, can be triggered not only endogenously but also exogenously. Some compounds (natural or synthetic) applied previously at low concentrations can lead to a greater tolerance to stress and be effectively used as elicitors [69].

The beneficial effect of salicylic acid on yield may be related to its role in reducing the absorption of Na^+ and increasing the uptake of N, P, K, Ca, and Mg by plants [70]. In addition, SA reduces oxidative damage and favors osmotic adjustment, increasing the activities of antioxidant enzymes and the concentrations of soluble sugars and proteins under salt stress [45,46].

An increase in yield due to foliar application of salicylic acid was also reported by [20] in hydroponic melon under salt stress (EC ranging from 2.1 to 5.4 dS m^{-1}); the authors found that foliar application of salicylic acid at the concentration of 1.5 mM associated with EC of 3.1 dS m^{-1} promoted the maximum estimated value of 23.82 t ha^{-1} .

It is worth pointing out that the okra cultivation cycle in the second experiment was reduced by 13 days compared to the first experiment, which may be related to the increase in EC levels and to the climatic conditions (Figure 1), which were different during the experiments. In Experiment I, a mean temperature of $30.1 \text{ }^\circ\text{C}$ and a mean relative air humidity of 48.5% were observed, while in Experiment II, an average temperature of $27.3 \text{ }^\circ\text{C}$ and an average relative air humidity of 70% were observed.

The production data obtained in the first and second experiments were used to determine the tolerance of okra plants to the salinity of the nutrient solution, through the relative production, obtained by the plateau followed by the linear decrease model (Figure 18), in which the EC of 2.54 dS m^{-1} was obtained as salinity threshold, with a reduction of 7.98% per unit increment in EC, above this threshold value. However, it is possible to obtain a relative production of 70% with an EC of 6.3 dS m^{-1} and a relative production of 50% with an EC of 8.8 dS m^{-1} . On the other hand, using an electrical conductivity of the nutrient solution equal to or greater than 15.08 dS m^{-1} will lead to a relative production of 0%.

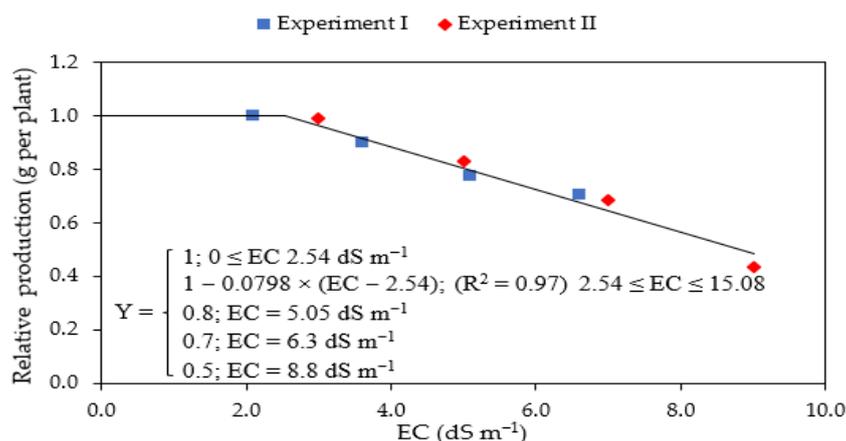


Figure 18. Relative production of ‘Canindé’ okra cultivated in a hydroponic system as a function of the electrical conductivity of the nutrient solution (EC), described by the plateau followed by the linear decrease model proposed by [30], calculated considering the productions obtained at the EC of $2.1\text{--}6.6 \text{ dS m}^{-1}$ (Experiment I—blue squares) and $3.0\text{--}9.0 \text{ dS m}^{-1}$ (Experiment II—red rhombuses).

According to criteria of tolerance levels, on a relative production basis, cited by [35], ‘Canindé’ okra cultivated in the hydroponic system can be considered as tolerant to salinity up to $\text{EC} = 5.05 \text{ dS m}^{-1}$, corresponding to the maximum losses of 20% in yields. However, the results obtained in this study showed that foliar application of salicylic acid at intermediate concentrations can induce the acclimatization of plants to salt stress, increasing the CO_2 assimilation rate and instantaneous carboxylation efficiency, resulting in higher yield. It is important to highlight that hydroponic production of okra, as for other vegetables, is an alternative for generating employment and revenues in arid and semi-arid regions, allowing greater control of irrigation water salinity and reduction of phytosanitary practices without causing environmental impacts such as soil salinization.

5. Conclusions

The increase in the electrical conductivity of the nutrient solution negatively affects the gas exchanges, relative water content, quantum efficiency of photosystem II, electron transport rate, and production components of okra plants grown in hydroponic systems. However, foliar application of salicylic acid at concentrations between 1.2 and 2.3 mM reduces the harmful effects of salt stress and can enable the use of saline water in okra cultivation in semi-arid regions. The salinity threshold for hydroponic cultivation of okra is 2.54 dS m^{-1} in the nutrient solution, with a reduction of 7.98% per unit increment in EC, from this threshold. It is possible to obtain a relative potential yield of 70% using a nutrient solution with electrical conductivity of 6.3 dS m^{-1} .

Author Contributions: Conceptualization, A.J.T.M. and G.S.d.L.; methodology, A.J.T.M. and V.K.N.O.; software, A.A.R.d.S.; validation, A.J.T.M., G.S.d.L. and L.A.d.A.S.; formal analysis, A.A.R.d.S. and L.A.d.A.S.; investigation, A.J.T.M. and V.K.N.O.; resources, G.S.d.L. and L.A.d.A.S.; data collection, A.A.R.d.S.; writing—original draft preparation, A.J.T.M. and G.S.d.L.; writing—review and editing, A.A.R.d.S., G.S.d.L., C.A.V.d.A., V.L.A.d.L., C.F.d.L., H.R.G. and P.D.F.; supervision, H.R.G.; project administration, G.S.d.L. and L.A.d.A.S.; All authors have read and agreed to the published version of the manuscript.

Funding: CNPq (National Council for Scientific and Technological Development, Proc. 131405/2021-7), CAPES (Coordination for the Improvement of Higher Education Personnel), and UFCG (Universidade Federal de Campina Grande).

Acknowledgments: The authors thank the Graduate Program in Agricultural Engineering of the Federal University of Campina Grande, the National Council for Scientific and Technological Development (CNPq), and the Coordination for the Improvement of Higher Education Personnel (CAPES) for the support in carrying out this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Nobre, R.G.; de Lima, G.S.; Gheyi, H.R.; Medeiros, E.P.D.; Soares, L.A.A.; Alves, A.N. Oil content and yield of castor bean as affected by nitrogen fertilization and saline water irrigation. *Pesqui. Agropecu. Bras.* **2012**, *47*, 991–999. [[CrossRef](#)]
2. Veloso, L.L.S.A.; Nobre, R.G.; de Lima, G.S.; Barbosa, J.L.; Melo, E.M.; Gheyi, H.R.; Gonçalves, E.B.; Souza, C.M.A. Quality of sourp (*Annona muricata* L.) seedlings under different water salinity levels and nitrogen fertilization. *Aust. J. Crop Sci.* **2018**, *12*, 306–310. [[CrossRef](#)]
3. Silva, A.A.R.; Veloso, L.L.S.A.; de Lima, G.S.; Soares, L.A.A.; Chaves, L.H.G.; Silva, F.A.; Fernandes, P.D. Induction of salt stress tolerance in cherry tomatoes under different salicylic acid application methods. *Semin. Cienc. Agrar.* **2022**, *43*, 1145–1166. [[CrossRef](#)]
4. Liang, W.; Ma, X.; Wan, P.; Liu, L. Plant salt-tolerance mechanism: A review. *Biochem. Biophys. Res. Commun.* **2018**, *495*, 286–291. [[CrossRef](#)] [[PubMed](#)]
5. Najar, R.; Aydi, S.; Sassi-Aydi, S.; Zarai, A.; Abdelly, C. Effect of salt stress on photosynthesis and chlorophyll fluorescence in *Medicago truncatula*. *Plant Biosyst.* **2019**, *153*, 88–97. [[CrossRef](#)]
6. Chen, C.Y.; Wang, S.W.; Kim, H.; Pan, S.Y.; Fan, C.; Lin, Y.J. Non-conventional water reuse in agriculture: A circular water economy. *Water Res.* **2021**, *199*, e117193. [[CrossRef](#)] [[PubMed](#)]
7. Adekiya, A.O.; Dahunsi, S.O.; Ayeni, J.F.; Aremu, C.; Aboyeji, C.M.; Okunlola, F.; Oyelami, A.E. Organic and in-organic fertilizers effects on the performance of tomato (*Solanum lycopersicum*) and cucumber (*Cucumis sativus*) grown on soilless medium. *Sci. Rep.* **2022**, *12*, 12212. [[CrossRef](#)] [[PubMed](#)]
8. Silva, A.A.R.; Sousa, P.F.N.; de Lima, G.S.; Soares, L.A.A.; Gheyi, H.R.; Azevedo, C.A.V. Hydrogen peroxide reduces the effect of salt stress on growth and postharvest quality of hydroponic mini watermelon. *Water Air Soil Pollut.* **2022**, *233*, 198. [[CrossRef](#)]
9. Soares, T.M.; Duarte, S.N.; Silva, E.F.F.; Paz, V.P.S.; Oliveira, J.L.B. Uso de águas salobras em sistemas hidropônicos de cultivo. In *Manejo da Salinidade na Agricultura: Estudos Básicos e Aplicados*; Gheyi, H.R., Dias, N.S., Lacerda, C.F., Gomes Filho, É., Eds.; INCT Sal: Fortaleza, Brazil, 2016; pp. 373–393.
10. Rodrigues, L.R.F. *Técnicas de Cultivo Hidropônico e de Controle Ambiental No Manejo de Pragas, Doenças e Nutrição Vegetal em Ambiente Protegido*; FUNEP: Jaboticabal, Brazil, 2022; 762p.
11. De Freitas, F.T.O.; Soares, T.M.; da Silva, M.G.; Rafael, M.R.S. Cultivo de alface sob intervalos de recirculações das soluções nutritivas em sistemas hidropônicos usando água salobra. *Irriga* **2021**, *1*, 67–96. [[CrossRef](#)]
12. Nazar, R.; Umar, S.; Khan, N.A.; Sareer, O. Salicylic acid supplementation improves photosynthesis and growth in mustard through changes in proline accumulation and ethylene formation under drought stress. *S. Afr. J. Bot.* **2015**, *98*, 84–94. [[CrossRef](#)]
13. Moustafa-Farag, M.; Mohamed, H.I.; Mahmoud, A.; Elkesh, A.; Misra, A.N.; Guy, K.M.; Zhang, M. Salicylic acid stimulates antioxidant defense and osmolyte metabolism to alleviate oxidative stress in watermelons under excess boron. *Plants* **2020**, *9*, 724. [[CrossRef](#)] [[PubMed](#)]
14. Lacerda, C.N.; de Lima, G.S.; Soares, L.A.A.; de Fátima, R.T.; Gheyi, H.R.; Azevedo, C.A.V. Morphophysiology and production of guava as a function of water salinity and salicylic acid. *Rev. Bras. Eng. Agrícola Ambient.* **2022**, *26*, 451–458. [[CrossRef](#)]
15. Roshdy, A.E.; Alebidi, A.; Almutairi, K.; Al-Obeed, R.; Elsabagh, A. The effect of salicylic acid on the performances of salt stressed strawberry plants, enzymes activity, and salt tolerance index. *Agronomy* **2021**, *11*, 775. [[CrossRef](#)]
16. Silva, A.A.R.; de Lima, G.S.; de Azevedo, C.A.V.; Veloso, L.L.S.A.; Gheyi, H.R. Salicylic acid as an attenuator of salt stress in sourp. *Rev. Caatinga.* **2020**, *33*, 1092–1101. [[CrossRef](#)]
17. Veloso, L.L.S.A.; de Lima, G.S.; da Silva, A.A.R.; Souza, L.P.; de Lacerda, C.N.; Silva, I.J.; Fernandes, P.D. Attenuation of salt stress on the physiology and production of bell peppers by treatment with salicylic acid. *Semin. Cienc. Agrar.* **2021**, *42*, 2751–2768. [[CrossRef](#)]

18. Silva, E.B.; Viana, T.V.A.; de Sousa, G.G.; Sousa, J.; dos Santos, M.F.; Azevedo, B.M. Growth and nutrition of peanut crop subjected to saline stress and organomineral fertilization. *Rev. Bras. Eng. Agric. Ambient.* **2022**, *26*, 495–501. [[CrossRef](#)]
19. Sousa, V.F.O.; Santos, A.S.; Sales, W.S.; Silva, A.J.; Gomes, F.A.L.; Dias, T.J.; Araújo, J.R.E.S. Exogenous application of salicylic acid induces salinity tolerance in eggplant seedlings. *Braz. J. Biol.* **2022**, *84*, e257739. [[CrossRef](#)] [[PubMed](#)]
20. Soares, M.D.M.; Dantas, M.V.; de Lima, G.S.; Oliveira, V.K.N.; Soares, L.A.A.; Gheyi, H.R.; Fernandes, P.D. Physiology and yield of ‘Gaúcho’ melon under brackish water and salicylic acid in hydroponic cultivation. *Arid. Land Res. Manag.* **2022**, *1*, 1–20. [[CrossRef](#)]
21. Silva, M.G.D.; Soares, T.M.; Gheyi, H.R.; Santos, C.C.D.; Oliveira, M.G.B. Hydroponic cultivation of coriander intercropped with rocket subjected to saline and thermal stresses in the root-zone. *Rev. Ceres* **2022**, *69*, 148–157. [[CrossRef](#)]
22. Silva, T.I.; Silva, J.S.; Dias, M.G.; Martins, J.V.S.; Ribeiro, W.S.; Dias, T.J. Salicylic acid attenuates the harmful effects of salt stress on basil. *Rev. Bras. Eng. Agric. Ambient.* **2022**, *26*, 399–406. [[CrossRef](#)]
23. Soares, L.A.A.; da Silva, R.G.; de Lima, G.S.; Sales, G.N.B.; da Costa, F.B.; Silva Neta, A.M.S.; Gomes, J.P. Preservation by lactic fermentation and physicochemical characterization of okra produced under water salinity and potassium fertilization. *Semin. Cienc. Agrar.* **2020**, *41*, 2495–2508. [[CrossRef](#)]
24. Farias, D.B.S.; da Silva, P.S.O.; Lucas, A.A.T.; de Freitas, M.I.; Santos, T.J.; Fontes, P.T.N.; Oliveira Júnior, L.F.G. Physiological and productive parameters of the okra under irrigation levels. *Sci. Hortic.* **2019**, *252*, 1–6. [[CrossRef](#)]
25. Abubaker, B.M.A.; Ahadi, M.; Shuang-En, Y.; Guang-Cheng, S. Different irrigation methods for okra crop production under semi-arid conditions. *Int. J. Eng. Res. Technol.* **2014**, *3*, 787–794.
26. Hoagland, D.R.; Arnon, D.I. *The Water-Culture Method for Growing Plants without Soil*; University of California, Circular, California Agricultural Experiment Station: Oakland, CA, USA, 1950; 32p.
27. Isla. Available online: <https://www.isla.com.br/arquivos-para-download/catalogos> (accessed on 5 August 2022).
28. Medeiros, J.F.; Lisboa, R.A.; de Oliveira, M.; de Silva Júnior, M.J.; Alves, L.P. Caracterização das águas subterrâneas usadas para irrigação na área produtora de melão da Chapada do Apodi. *Rev. Bras. Eng. Agric. Ambient.* **2003**, *7*, 469–472. [[CrossRef](#)]
29. Weatherley, P. Studies in the water relations of the cotton plant. I. The field measurement of water deficits in leaves. *New Phytol.* **1950**, *49*, 81–97. [[CrossRef](#)]
30. Scotti-Campos, P.; Pham-Thi, A.T.; Semedo, J.N.; Pais, I.P.; Ramalho, J.C.; Matos, M.C. Physiological responses and membrane integrity in three Vigna genotypes with contrasting drought tolerance. *Emir. J. Food Agric.* **2013**, *25*, 1002–1013. [[CrossRef](#)]
31. Sá, F.V.D.S.; Brito, M.; Silva, L.D.A.; Moreira, R.C.L.; Fernandes, P.D.; De Figueiredo, L.C. Fisiologia da percepção do estresse salino em híbridos de tangerineira—Sunki Comum sob solução hidropônica salinizada. *Comun. Sci.* **2015**, *6*, 463–470. [[CrossRef](#)]
32. Mota, W.F.; Finger, F.L.; Casali, V.W.D. *Olericultura: Melhoramento Genético do Quiabeiro*; Universidad Federal de Viçosa, Departamento de Fitotecnia: Viçosa, Brazil, 2000; 144p.
33. Maas, E.V.; Hoffman, G.J. Crop salt tolerance-current assessment. *J. Irrig. Drain. Div. ASCE.* **1977**, *103*, 115–134. [[CrossRef](#)]
34. Bione, M.A.A.; Soares, T.M.; Cova, A.M.W.; Silva Paz, V.P.; Gheyi, H.R.; Rafael, M.R.S.; Neves, B.S.L. Hydroponic production of ‘Biquinho’ pepper with brackish water. *Agric. Water Manag.* **2021**, *245*, e106607. [[CrossRef](#)]
35. Fageria, N.K.; Gheyi, H.R. Melhoramento genético das culturas e seleção de cultivares. In *Manejo e Controle da Salinidade na Agricultura Irrigada*; Gheyi, H.R., Queiroz, J.D., de Medeiros, J.F., Eds.; UFPB: Campina Grande, Brazil, 1997; pp. 365–385.
36. Ferreira, D.F. SISVAR: A computer analysis system to fixed effects split-plot type designs. *Rev. Bras. Biom.* **2019**, *37*, 529–535. [[CrossRef](#)]
37. Majeedand, A.; Muhammad, Z. Salinity: A major agricultural problem-causes, impacts on crop productivity and management strategies. *Plant Abiotic Stress Toler.* **2019**, *1*, 83–99. [[CrossRef](#)]
38. Khatami, S.A.; Kasraie, P.; Oveysi, M.; Moghadam, H.R.T.; Ghooshchi, F. Mitigating the adverse effects of salinity stress on lavender using biodynamic preparations and bio-fertilizers. *Ind. Crops Prod.* **2022**, *183*, e114985. [[CrossRef](#)]
39. da Silva, A.A.R.; de Lima, G.S.; de Azevedo, C.A.V.; Gheyi, H.R.; de Souza, A.R.; Fernandes, P.D. Salicylic acid relieves the effect of saline stress on soursop morphophysiology. *Ciênc. Agrotecnologia* **2021**, *45*, e007021. [[CrossRef](#)]
40. Ali, M.; Kamran, M.; Abbasi, G.H.; Saleem, M.H.; Ahmad, S.; Parveen, A.; Fahad, S. Melatonin-induced salinity tolerance by ameliorating osmotic and oxidative stress in the seedlings of two tomato (*Solanum lycopersicum* L.) cultivars. *J. Plant Growth Regul.* **2021**, *40*, 2236–2248. [[CrossRef](#)]
41. Batista, M.C.; Nascimento, R.D.; Júnior, S.D.O.M.; Nascimento, E.C.S.; Bezerra, C.V.D.C.; de Lima, R.F. Physiology and production of cherry tomato cultivars in a hydroponic system using brackish water. *Rev. Bras. Eng. Agric. Ambient.* **2021**, *25*, 219–227. [[CrossRef](#)]
42. Sachdev, S.; Ansari, S.A.; Ansari, M.I.; Fujita, M.; Hasanuzzaman, M. Abiotic stress and reactive oxygen species: Generation, signaling, and defense mechanisms. *Antioxidants* **2021**, *10*, 277. [[CrossRef](#)]
43. Yudina, L.; Sukhova, E.; Gromova, E.; Nerush, V.; Vodeneev, V.; Sukhov, V. A light-induced decrease in the photochemical reflectance index (PRI) can be used to estimate the energy-dependent component of non-photochemical quenching under heat stress and soil drought in pea, wheat, and pumpkin. *Photosynth. Res.* **2020**, *146*, 175–187. [[CrossRef](#)]
44. Sullivan, C.Y. Mechanisms of heat drought resistance in grain sorghum and methods of measurement. In *Sorghum in Seventies*; Rao, N.G.P., House, L.R., Eds.; Oxford and IBH Publ. Co.: New Delhi, India, 1971; 247p.
45. Herrera-Vásquez, A.; Salinas, P.; Holuigue, L. Salicylic acid and reactive oxygen species interplay in the transcriptional control of defense genes expression. *Front. Plant Sci.* **2015**, *6*, 171–179. [[CrossRef](#)] [[PubMed](#)]

46. Batista, V.C.V.; Pereira, I.M.C.; Paulo-Marinho, S.O.; Canuto, K.M.; Pereira, R.C.A.; Rodrigues, T.H.S.; Daloso, D.M.; Gomes Filho, E.; de Carvalho, H.H. Salicylic acid modulates primary and volatile metabolites to alleviate salt stress-induced photosynthesis impairment on medicinal plant *Egletes viscosa*. *Environ. Exp. Bot.* **2019**, *167*, e103870. [[CrossRef](#)]
47. Silva, A.R.A.; Bezerra, F.M.L.; Lacerda Filho, C.F.; Pereira Filho, J.V.; Freitas, C.A.S. Trocas gasosas em plantas de girassol submetidas à deficiência hídrica em diferentes estádios fenológicos. *Rev. Ciênc. Agron.* **2013**, *44*, 86–93. [[CrossRef](#)]
48. Dias, A.S.; de Lima, G.S.; Sá, F.V.S.; Gheyi, H.R.; Soares, L.A.A.; Fernandes, P.D. Gas exchanges and photochemical efficiency of West Indian cherry cultivated with saline water and potassium fertilization. *Rev. Bras. Eng. Agrícola Ambient.* **2018**, *22*, 628–633. [[CrossRef](#)]
49. Fernandes, C.D.S.; Ferreira-Neto, M.; Dias, N.D.S.; Reges, L.B.L.; Silva, L.D.A.; Moreira, R.C.L.; da Silva, A.; de Paiva, E.P.; Fernandes, P.D.; Sá, F.V.D.S. The appropriate source of nitrogen for Italian Zucchini under salt stress conditions. *J. Soil Sci. Plant Nutr.* **2022**, *22*, 560–570. [[CrossRef](#)]
50. van Zelm, E.; Zhang, Y.; Testerink, C. Salt tolerance mechanisms of plants. *Annu. Rev. Plant Biol.* **2020**, *71*, 403–433. Available online: <http://www.annualreviews.org/eprint/VN2EH6PPXYXVDSWUTZEM/full/10.1146/annurev-arplant-050718-100005> (accessed on 10 August 2022). [[CrossRef](#)] [[PubMed](#)]
51. Sousa, G.G.; Mendonça, A.M.; Silva, J.R.S.; Silva Junior, F.B.; Moraes, J.G.L.; Sousa, J.T.M. Morphophysiological characteristics of okra plants submitted to saline stress in soil with organic fertilizer. *Commun. Sci.* **2020**, *11*, e3241. [[CrossRef](#)]
52. Sales, J.R.S.; Magalhães, C.L.; Freitas, A.G.; Goes, G.F.; Sousa, H.C.; Sousa, G.G. Physiological indices of okra under organomineral fertilization and irrigated with salt water. *Rev. Bras. Eng. Agrícola Ambient.* **2021**, *25*, 466–471. [[CrossRef](#)]
53. Liu, Y.; Xi, M.; Li, Y.; Cheng, Z.; Wang, S.; Kong, F. Improvement in salt tolerance of *Iris pseudacorus* L. in constructed wetland by exogenous application of salicylic acid and calcium chloride. *J. Environ. Manag.* **2021**, *300*, e113703. [[CrossRef](#)]
54. Lee, S.Y.; Damodaran, P.N.; Roh, K.S. Influence of salicylic acid on rubisco and rubisco activase in tobacco plant grown under sodium chloride in vitro. *Saudi J. Biol. Sci.* **2014**, *21*, 417–426. [[CrossRef](#)]
55. Aires, E.S.; Ferraz, A.K.L.; Carvalho, B.L.; Teixeira, F.P.; Putti, F.F.; Souza, E.P.; Ono, E.O. Foliar application of salicylic acid to mitigate water stress in tomato. *Plants* **2022**, *11*, 1775. [[CrossRef](#)]
56. Poór, P.; Borbély, P.G.; Bódi, N.; Bagyánszki, M.; Görgényi, M.T.I. Effects of salicylic acid on photosynthetic activity and chloroplast morphology under light and prolonged darkness. *Photosynthetica* **2019**, *57*, 367–376. [[CrossRef](#)]
57. Aires, E.S.; Ferraz, A.K.L.; Carvalho, B.L.; Teixeira, F.P.; Rodrigues, J.D.; Ono, E.O. Foliar application of salicylic acid intensifies antioxidant system and photosynthetic efficiency in tomato plants. *Bragantia* **2022**, *81*, e1522. [[CrossRef](#)]
58. Sá, F.V.S.; Gheyi, H.R.; de Lima, G.S.; Pinheiro, F.W.A.; de Paiva, E.P.; Moreira, R.C.L.; Fernandes, P.D. The right combination of NPK fertilization may mitigate salt stress in custard apple (*Annona squamosa* L.). *Acta Physiol. Plant.* **2021**, *43*, 59. [[CrossRef](#)]
59. Silva, M.M.P.; Vasquez, H.M.; Bressan-Smith, R.; da Silva, J.F.C.; Erbesdobler, E.D.A.; Andrade Junior, P.S.C. Eficiência fotoquímica de gramíneas forrageiras tropicais submetidas à deficiência hídrica. *Rev. Bras. Zootec.* **2006**, *35*, 67–74. [[CrossRef](#)]
60. Tatagiba, S.D.; Moraes, G.A.B.K.; Nascimento, K.J.T.; Peloso, A.F. Limitações fotossintéticas em folhas de plantas de tomateiro submetidas a crescentes concentrações salinas. *Eng. Agri.* **2014**, *22*, 138–149. [[CrossRef](#)]
61. Sá, F.V.D.S.; Gheyi, H.R.; De Lima, G.S.; De Paiva, E.P.; Silva, L.D.A.; Moreira, R.C.L.; Fernandes, P.D.; Dias, A.S. Ecophysiology of West Indian cherry irrigated with saline water under phosphorus and nitrogen doses. *Biosci. J.* **2019**, *35*, 211–221. [[CrossRef](#)]
62. Larbi, A.; Baccar, R.; Boulal, H. Response of olive tree to ammonium nitrate fertilization under saline conditions. *J. Plant Nutr.* **2020**, *44*, 1432–1445. [[CrossRef](#)]
63. da Silva, J.S.; Sá, F.V.D.S.; Dias, N.D.S.; Neto, M.F.; Jales, G.D.; Fernandes, P.D. Morphophysiology of mini watermelon in hydroponic cultivation using reject brine and substrates. *Rev. Bras. Eng. Agrícola Ambient.* **2021**, *25*, 402–408. [[CrossRef](#)]
64. Siddiqui, S.A.; Khatri, K.; Patel, D.; Rathore, M.S. Photosynthetic gas exchange and chlorophyll a fluorescence in *Salicornia brachiata* (Roxb.) under osmotic stress. *J. Plant Growth Regul.* **2022**, *41*, 429–444. [[CrossRef](#)]
65. Silva, J.S.; Dias, N.S.; Jales, G.D.; Reges, L.B.L.; de Freitas, J.M.C.; Umbelino, B.F.; Sá, F.V.S. Physiological responses and production of mini-watermelon irrigated with reject brine in hydroponic cultivation with substrates. *Environ. Sci. Pollut. Res.* **2022**, *29*, 11116–11129. [[CrossRef](#)]
66. Modesto, F.J.N.; Dos Santos, M.C.M.; Soares, T.M.; Dos Santos, E.P.M. Crescimento, produção e consumo hídrico do quiabeiro submetido à salinidade em condições hidropônicas. *Irriga* **2019**, *24*, 2486–2497. [[CrossRef](#)]
67. DA Costa, L.F.; Soares, T.M.; DA Silva, M.G.; Modesto, F.J.N.; Queiroz, L.D.A.; Pereira, J.D.S. Cauliflower growth and yield in a hydroponic system with brackish water. *Rev. Caatinga.* **2020**, *33*, 1060–1070. [[CrossRef](#)]
68. Dantas, M.V.; de Lima, G.S.; Gheyi, H.R.; Pinheiro, F.W.A.; Silva, P.C.C.; Soares, L.A.A. Gas exchange and hydroponic production of zucchini under salt stress and H₂O₂ application. *Rev. Caatinga.* **2022**, *35*, 436–449. [[CrossRef](#)]
69. Antoniou, C.; Savvides, A.; Christou, A.; Fotopoulos, V. Unravelling chemical priming machinery in plants: The role of reactive oxygen–nitrogen–sulfur species in abiotic stress tolerance enhancement. *Curr. Opin. Plant Biol.* **2016**, *33*, 101–107. [[CrossRef](#)] [[PubMed](#)]
70. Farhangi-Abriz, S.; Ghassemi-Golezani, K. How can salicylic acid and jasmonic acid mitigate salt toxicity in soybean plants? *Ecotoxicol. Environ. Saf.* **2018**, *147*, 1010–1016. [[CrossRef](#)] [[PubMed](#)]