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Original Article

Salicylic acid does not relieve salt stress on gas exchange, chlorophyll fluorescence, and hydroponic melon growth

O ácido salicílico não alivia o estresse salino nas trocas gasosas, fluorescência da clorofila e crescimento hidropônico do meloeiro

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Abstract

The objective of this study was to evaluate the salicylic acid applications in attenuating the harmful effects of saline nutrient solution on the physiology and growth of 'Gaúcho' melon cultivated in the NFT hydroponic system. The experiment was conducted in a greenhouse, in Pombal–PB, Brazil. The cultivation system used was the Nutrient Film Technique - NFT hydroponics. A completely randomized split-plot design was used, with the plot referring to four levels of salinity in the nutrient solution - ECns (2.1 control, 3.2, 4.3, and 5.4 dS m^{-1}) and the sub-plot four concentrations of salicylic acid (SA) (0, 1.5, 3.0, and 4.5 mM), applied via foliar spray, with six replications. Nutrient solution of 4.3 and 5.4 dS m^{-1} electrical conductivity promotes higher maximum and variable fluorescence, respectively. The stomatal conductance, transpiration, stem diameter, main branch length, leaf dry mass, and stem dry mass of 'Gaúcho' melon plants decrease with the increase in salinity of the nutrient solution. Salicylic acid increases the initial fluorescence and the main branch length of 'Gaúcho' melon plants in hydroponic cultivation. Salicylic acid at a concentration of 1.5 to 4.5 mM did not attenuate the effects of salt stress on the internal CO_2 concentration, CO_2 assimilation rate, and root dry mass of 'Gaúcho' melon plants.

Keywords: *Cucumis melo* L., phytohormone, phytomass, salinity, plant physiology, nutrient film technique.

Resumo

O objetivo deste trabalho foi avaliar as aplicações do ácido salicílico como atenuador dos efeitos deletérios da solução nutritiva salina sobre a fisiologia e o crescimento do melão 'Gaúcho' cultivado em sistema hidropônico NFT. O experimento foi conduzido em casa de vegetação, em Pombal – PB, Brasil. O sistema de cultivo utilizado foi a técnica do fluxo laminar de nutrientes - NFT. Foi utilizado um delineamento inteiramente casualizado em parcelas subdivididas, sendo a parcela referente a quatro níveis de salinidade de solução nutritiva - CEsn (2,1 controle, 3,2, 4,3 e 5,4 dS m^{-1}) e a subparcelas quatro concentrações de ácido salicílico - AS (0, 1,5, 3,0 e 4,5 mM), aplicado via pulverização foliar, com seis repetições. A solução nutritiva de 4,3 e 5,4 dS m^{-1} condutividade elétrica promove maior fluorescência máxima e variável, respectivamente. A condutância estomática, a transpiração, o diâmetro do caule, o comprimento do ramo principal, a massa seca da folha e a massa seca do caule do meloeiro 'Gaúcho' diminuiu com o aumento da salinidade da solução nutritiva. O ácido salicílico aumenta a fluorescência inicial e o comprimento do ramo principal do meloeiro 'Gaúcho' em cultivo hidropônico. O ácido salicílico na concentração de 1,5 a 4,5 mM não atenuou os efeitos do estresse salino sobre a concentração interna de CO_2, taxa de assimilação de CO_2 e massa seca da raiz do meloeiro 'Gaúcho'.

Palavras-chave: *Cucumis melo* L., fitormônio, fitomassas, salinidade, fisiologia vegetal, técnica do fluxo laminar de nutrientes.

1. Introduction

Melon (*Cucumis melo* L.) is an annual crop, which adapts to the climatic conditions of northeastern Brazil, producing fruits rich in vitamin C with export potential (Rocha et al., 2021). This fruit crop has great economic and social importance for the Brazilian Northeast because this region has the highest national production and acts in the creation of employment opportunities. The states of Rio Grande do Norte and Ceará are the largest melon producers in Brazil, accounting for 375,574 and 73,838 tons in 2020, respectively (IBGE, 2020).

Water scarcity in the semi-arid region of northeastern Brazil, due to low precipitation, high temperatures, and

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high evaporation, hampers agricultural production, causing producers to use alternative sources such as well and reservoirs that usually have waters with high concentrations of salts, a limiting factor for the expansion of irrigated agriculture and income generation (Corwin, 2021; Silva et al., 2022; Pinheiro et al., 2022b).

Excess salts in irrigation water provoke osmotic effect that cause a reduction in stomatal conductance, internal CO_2 concentration, and CO_2 assimilation rate, limiting water absorption, essential in the photosynthetic process, in addition to the accumulation of toxic ions in plant tissues, which destabilizes metabolic and biochemical functioning (Soares et al., 2018; Dantas et al., 2021; Silva et al., 2021a; Lacerda et al., 2022).

Faced with this problem, researchers have been intensively seeking strategies capable of alleviating the effects of salt stress on plants. These alternatives particularly include foliar application of salicylic acid. Salicylic acid is a phenolic compound that, when applied at the appropriate concentration, signals the defense mechanism of plants to produce enzymatic compounds (catalase, glutathione, and peroxidase) and non-enzymatic compounds (carotenoids, glutathione, and ascorbic acid) to detoxify reactive oxygen species (Koo et al., 2020; Ghassemi-Golezani and Farhadi, 2022; Dehnavi et al., 2022).

Hydroponic cultivation is another strategy that allows the control of electrical conductivity, pH, amount of nutrients in the nutrient solution, and higher water use efficiency compared to conventional cultivation, besides enabling production throughout the year in a greenhouse, hence being an advantageous form of cultivation for the northeastern semi-arid conditions (Loureiro et al., 2019; Leal et al., 2020).

In this context, the objective of this study was to evaluate the salicylic acid applications in attenuating the deleterious effects of saline nutrient solution on the physiology and growth of 'Gaúcho' melon cultivated in the NFT hydroponic system.

2. Material and Methods

2.1. Site description and experimental design

The experiment was carried out in a greenhouse at the Center of Science and Agrifood Technology (CCTA) of the Federal University of Campina Grande (UFCG), in Pombal, Paraiba, Brazil, at the geographic coordinates: 6°46'13" South latitude and 37°48'6" West longitude, at an average altitude of 184 m. Data of maximum and minimum temperatures and relative humidity of air collected during the experimental period are shown in Figure 1.

A completely randomized split-plot design was used, with the plot referring to four levels of salinity in the nutrient solution - ECns (2.1 - control, 3.2, 4.3, and 5.4 dS m^{-1}) and the sub-plot four concentrations of salicylic acid (SA) (0, 1.5, 3.0, and 4.5 mM), applied via foliar spray, with six replications.

2.2. Description of treatments

The salinity levels of the nutrient solution were established based on the study carried out by Dantas et al. (2021) and SA concentrations, according to the results reported by Silva et al. (2021a) for the soursop crop.

The nutrient solution was prepared according to the recommendations of Hoagland and Arnon (1950), presented in Table 1. The addition of the recommended nutrient concentrations to the supply water (0.3 dS m^{-1}) resulted in an electrical conductivity of 2. 1 dS m^{-1}, which is considered the control for the present study.

The saline nutrient solutions used in irrigation were obtained by adding sodium chloride (NaCl), calcium chloride ($CaCl_2.2H_2O$), and magnesium chloride ($MgCl_2.6H_2O$) salts, in the equivalent proportion of 7:2:1, respectively. This is the proportion of Na, Ca, and Mg commonly found in the waters employed for irrigation in the semi-arid region of northeastern Brazil (Medeiros, 1992). The waters were prepared in the laboratory considering the relationship

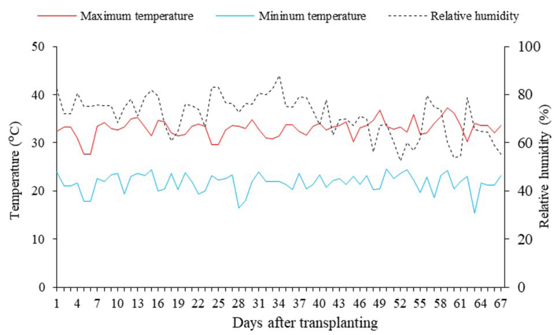


Figure 1. Temperature (maximum and minimum) and relative humidity of air during the experimental period.

Table 1. Chemical composition relative to nutrients present in the nutrient solution of Hoagland and Arnon (1950).

Fertilizer	Quantity g 1000L^{-1}
KH_2PO_4	136.09
KNO_3	101.10
$Ca(NO_3)_2.4H_2O$	236.15
$MgSO_4.7H_2O$	246.49
H_3BO_3	3.10
$MnSO_4.4H_2O$	1.70
$ZnSO_4.7H_2O$	0.22
$CuSO_4.5H_2O$	0.75
$(NH_4)_6Mo_7O_{24}. 4H_2O$	1.25
$CuSO_4$	0.75
EDTA – Na	13.9
$FeSO_4$	13.9

between ECw and concentration of salts (Richards, 1954), according to Equation 1:

$$Q \cong 10 \times ECsn \quad (1)$$

where:
Q = Sum of cations (mmol$_c$ L^{-1});
ECns = Desired electrical conductivity of nutrient solution after discounting electrical conductivity of water used to prepare solution (dS m^{-1}).

The concentrations of salicylic acid were prepared by diluting the substance in 100 mL of 30% ethyl alcohol and then completing it with distilled water until reaching the volume of 1 L, a necessary process due to the low solubility of the acid in water at room temperature. In the spraying, the commercial adhesive spreader Wil fix® (0.5 mL L^{-1}) was added because it has an adjuvant action, reducing the surface tension of the drops. Applications with salicylic acid started 10 days after transplanting (DAT) and 72 hours before starting the application of the saline nutrient solution. Four applications were performed at an interval of 15 days, by foliar spraying and wetting the abaxial and adaxial sides of leaves, using a manual sprayer between 5:00 and 6:00 p.m. Plastic curtains were used to prevent the acid from drifting onto plants of other treatments.

2.3. Conducting the experiment

Seeds of 'Gaúcho' melon (Caipira) were used in the present study. It is a cultivar that produces cylindrical fruits of orange color with longitudinal segments. It is a rustic plant with a prostrate growth habit. In addition, the pulp stands out for its excellent aroma and flavor and it is a variety with better adaptation to warm and mild temperatures.

Sowing was carried out in polyethylene containers with a 50 mL capacity containing coconut fiber, arranged in trays. Before sowing, coconut fiber was washed and dried outdoors. From germination to the emergence of the first true leaves, the seedlings received nutrient solution at half strength (50% of the recommended concentration). After the emergence of the second pair of true leaves, the seedlings were transplanted to the hydroponic structure and vertically supported with stakes, leaving only the main branch and branch with the fruit. When necessary, phytosanitary treatments were performed. After plants were transplanted in the hydroponic systems, nutrient solution at full strength (100%) was used.

The hydroponic system was Nutrient Film Technique - NFT type, made of polyvinyl chloride (PVC) pipe 100 mm in diameter and six meters in length, spaced 0.80 m apart. In the channels, the spacing was 0.50 m between plants and 1.0 m between treatments.

The channels were supported on sawhorses with 0.60 m height at a 4% slope for the nutrient solution to flow. At the lowest part of each bench in the hydroponic system, a 150 L polyethylene recipient was placed to collect and conduct the nutrient solution to the channels. The nutrient solution was injected into the cultivation channels by a pump (35 W), at a flow rate of 3 L min^{-1}. Nutrient solution circulation was programmed by a timer, with an intermittent flow of 15 min.

Nutrient solution pH and electrical conductivity were checked daily, maintaining the ECns according to the established treatments and the pH between 5.5 and 6.5 When necessary, the ECns were adjusted by adding public-supply water (ECw=0.3 dS m^{-1}), and the pH by adding 0.1 M KOH or HCl. However, the nutrient solution was completely replaced at eight-day intervals.

2.4. Analysed variables

The effect of the treatments was measured at 57 days after placing the plants in the hydroponic profiles, based on gas exchange, photochemical efficiency, and growth. Gas exchange was measured by stomatal conductance - *gs* (mol H_2O m^{-2} s^{-1}), transpiration - *E* (mmol H_2O m^{-2} s^{-1}), CO_2 assimilation rate- *A* (µmol CO_2 m^{-2} s^{-1}), and internal CO_2 concentration – *Ci* (µmol CO_2 mol^{-1}) using a portable infrared carbon dioxide analyzer (IRGA), LCPro+ Portable Photosynthesis System® model (ADC BioScientific Limited, UK). The readings were carried out between 6:30 and 10:00 a.m., in a fully expanded leaf blade under natural conditions of air temperature and CO_2 concentration using an artificial source of radiation established through the photosynthetic response curve to light (1200 µmol photons m^{-2} s^{-1}) (Fernandes et al., 2021).

At the same time, chlorophyll *a* fluorescence parameters were evaluated through the initial (F_0), maximum (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm) in leaves of the middle third, fully expanded and pre-adapted to the dark for 30 minutes, using Opti Science's O55p pulse-modulated fluorometer.

Growth was evaluated by the number of leaves - NL, obtained by counting fully expanded leaves with a minimum length of 3 cm; stem diameter - SD (mm), measured 5 cm above the hydroponic system, using a digital caliper; and main branch length - MBL (cm), measured with a graduated ruler as the distance between the collar and the apical meristem.

After biometric measurements, the plants were collected, separated into different parts, placed in properly identified paper bags, and dried in a forced air circulation oven, maintained at 65 ºC, until reaching constant weight. Subsequently, dry mass of leaves (LDM), stem (SDM), and root (RDM) were obtained by weighing on a scale with 0.01 g resolution. Root/shoot ratio (R/S) was also calculated, obtained by the coefficient between root dry mass and shoot dry mass.

2.5. Statistical analyses

The data were subjected to the normality test and analyzed by the F test at a 0.05 probability level and, when significant, polynomial regression analysis (linear and quadratic) was performed for nutrient solution salinity and for salicylic acid concentrations using the statistical program SISVAR - ESAL version 5.7 (Ferreira, 2019). In cases where there was a significant interaction between the factors, the Table Curve 3D software was used to obtain the response surface curves.

3. Results

According to the summary of analysis of variance (Table 2), there was a significant interaction between the factors (ECns × SA) for the internal CO_2 concentration and the CO_2 assimilation rate of melon plants. Nutrient solution salinity significantly affected all variables studied. Salicylic acid significantly influenced the internal CO_2 concentration.

The increase in nutrient solution salinity caused a linear reduction in the stomatal conductance and transpiration of 'Gaúcho' melon plants, with decreases of 5.55 and 4.96% per unit increment of ECns, respectively (Figure 2A-2B). When comparing plants subjected to the highest salinity level (5.4 dS m^{-1}) to those that received ECns of 2.1 dS m^{-1}, reductions of 20.73 and 18.27% were observed in *gs* and *E*, respectively.

For internal CO_2 concentration (Figure 3A), plants under nutrient solution salinity of 2.1 dS m^{-1} and foliar application of salicylic acid at the concentration of 1.0 mM obtained the highest value (181.85 µmol CO_2 mol^{-1}). On the other hand, a minimum value of 135.53 µmol CO_2 mol^{-1} was found in plants subjected to the ECns of 5.4 dS m^{-1} and foliar application of SA at 4.5 mM.

Regarding the CO_2 assimilation rate, the maximum value of 38.60 µmol CO_2 m^{-2} s^{-1} was obtained in plants subjected to ECns of 2.1 dS m^{-1} and SA concentration of 2.4 mM, respectively (Figure 3B). The minimum value of 29.92 µmol CO_2 m^{-2} s^{-1} was obtained at the highest salinity level of the nutrient solution (ECns =5.4 dS m^{-1}) and salicylic acid concentration of 4.5 mM.

As observed in Table 3, there is a significant effect of nutrient solution salinity level on the maximum fluorescence (Fm) and variable fluorescence (Fv) of 'Gaúcho' melon plants. Salicylic acid concentrations significantly affected initial fluorescence (F_0). The interaction between the factors (ECns × SA) did not significantly influence any of the fluorescence variables measured in 'Gaúcho' melon.

Table 2. Summary of the analysis of variance for stomatal conductance (*gs*), transpiration (E), CO_2 assimilation rate (*A*), and internal CO_2 concentration (*Ci*) of 'Gaúcho' melon plants cultivated under nutrient solution salinity (ECns) and foliar application of salicylic acid (SA) in a hydroponic system, 57 days after transplantation.

Sources of variation	DF	Mean squares			
		gs	***E***	***A***	***Ci***
Nutrient solution salinity (ECns)	3	0.08^{**}	5.92^{**}	442.71^{**}	1743.44^{**}
Linear Regression	1	0.20^{**}	17.00^{**}	1286.84^{**}	5227.20^{**}
Quadratic Regression	1	0.02^{ns}	0.38^{ns}	19.41^{ns}	1.50^{ns}
Residual 1	15	0.005	0.56	22.22	110.05
Salicylic acid (SA)	3	0.01^{ns}	0.14^{ns}	17.86^{ns}	2834.41^{**}
Linear Regression	1	0.01^{ns}	0.0009^{ns}	0.0002^{ns}	6885.67^{**}
Quadratic Regression	1	0.003^{ns}	0.22^{ns}	53.53^{ns}	1617.04^{**}
Residual 2	60	0.005	0.37	13.42	225.42
Interaction (ECns × SA)	9	0.009^{ns}	0.78^{ns}	52.45^{**}	501.36^{*}
CV 1 (%)		13.37	13.45	13.70	6.35
CV 2 (%)		13.93	10.92	10.65	9.09

CV = coefficient of variation. DF- degree of freedom. ^{ns} = not significant. * = significant at $p \le 0.05$. ** = significant at ≤ 0.01.

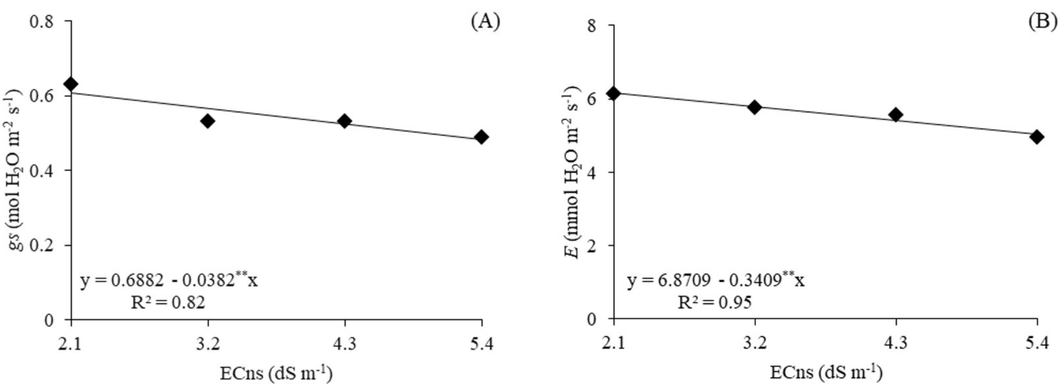
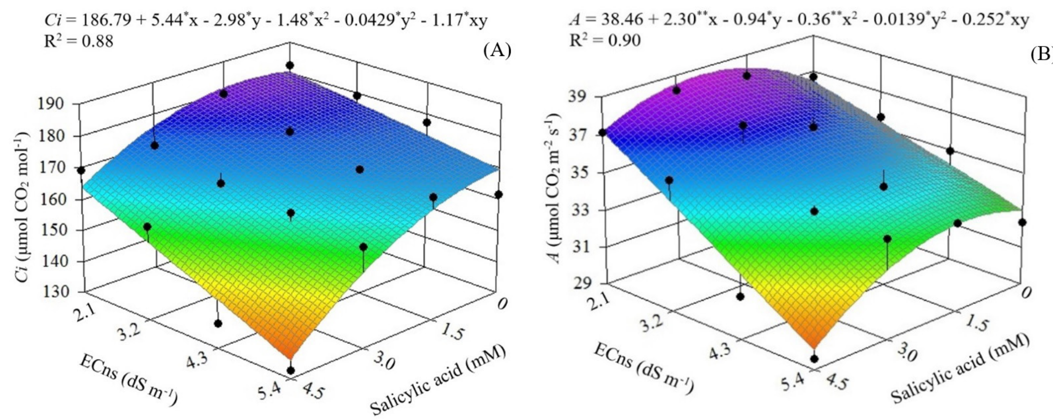


Figure 2. Stomatal conductance - *gs* (A) and transpiration - *E* (B) of 'Gaúcho' melon plants, as a function of the salinity of the nutrient solution - ECns, in hydroponic cultivation, 57 days after transplanting.



X and Y correspond to ECns and salicylic acid concentrations, respectively.

Figure 3. Internal CO_2 concentration - *Ci* (A) and CO_2 assimilation rate - *A* (B) of 'Gaúcho' melon plants, as a function of the interaction between the salinity level of the nutrient solution - ECns and foliar application of salicylic acid, in hydroponic cultivation, 57 days after transplanting.

Table 3. Summary of the analysis of variance for initial fluorescence (F_0), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm) of 'Gaúcho' melon plants cultivated under nutrient solution salinity (ECns) and foliar application of salicylic acid (SA) in a hydroponic system, 57 days after transplantation.

Sources of variation	DF	Mean squares			
		F_0	Fm	Fv	Fv/Fm
Nutrient solution salinity (ECns)	3	8633.15^{ns}	148894.30**	90161.56**	0.0010^{ns}
Linear Regression	1	755.00^{ns}	332432.13**	144699.07**	0.0000^{ns}
Quadratic Regression	1	20242.04^{ns}	104940.37^{ns}	86400.00*	0.0003^{ns}
Residual 1	15	3819.61	43800.17	22760.74	0.0014
Salicylic acid (SA)	3	13075.01*	48232.69^{ns}	4720.15^{ns}	0.0017^{ns}
Linear Regression	1	28152.03**	117876.00^{ns}	9594.40^{ns}	0.0043^{ns}
Quadratic Regression	1	7776.00^{ns}	1650.04^{ns}	1962.04^{ns}	0.0001^{ns}
Residual 2	60	3320.59	29415.02	19055.98	0.0021
Interaction (ECns × SA)	9	4664.64^{ns}	58827.25^{ns}	27466.97^{ns}	0.0022^{ns}
CV 1 (%)		12.41	10.24	9.77	4.95
CV 2 (%)		11.57	8.39	8.94	6.01

CV = coefficient of variation. DF- degree of freedom. ^{ns} = not significant. * = significant at $p \leq 0.05$. **,= significant at ≤ 0.01.

For the maximum fluorescence of melon plants (Figure 4A), the ECns of 4.6 dS m^{-1} promoted a maximum value of 2105.21. The minimum value of 1930.94 was obtained with a nutrient solution salinity of 2.1 dS m^{-1}. Plants subjected to ECns of 5.4 dS m^{-1} increased their Fm by 8.17% compared to those grown under the lowest level of nutrient solution salinity (2.1 dS m^{-1}).

For the variable fluorescence of 'Gaúcho' melon plants (Figure 4B), the salinity of the nutrient solution had a quadratic influence, with the highest estimated maximum value (1591.50) obtained in plants grown under ECns of 4.4 dS m^{-1}. Plants subjected to the lowest salinity level of the nutrient solution (2.1 dS m^{-1}) had the lowest estimated value of Fv (1461.85).

Salicylic acid linearly increased the initial fluorescence of 'Gaúcho' melon plants (Figure 4C), by 3.22% for each 1.5 mM increase in SA concentration, resulting in a 9.22% gain in SA concentration of 5.4 mM.

Based on the analysis of variance summary (Table 4), there is a significant effect of the interaction between the salinity of the nutrient solution and salicylic acid (ECns × SA) on the root dry mass of 'Gaúcho' melon. As a single factor, ECns affected all studied variables, except the number of leaves. The concentration of salicylic acid significantly affected the length of the main branch of 'Gaúcho' melon.

For the stem diameter of 'Gaúcho' melon plants (Figure 5A), the maximum estimated value (8.96 mm) was obtained in plants grown under the lowest level of ECns

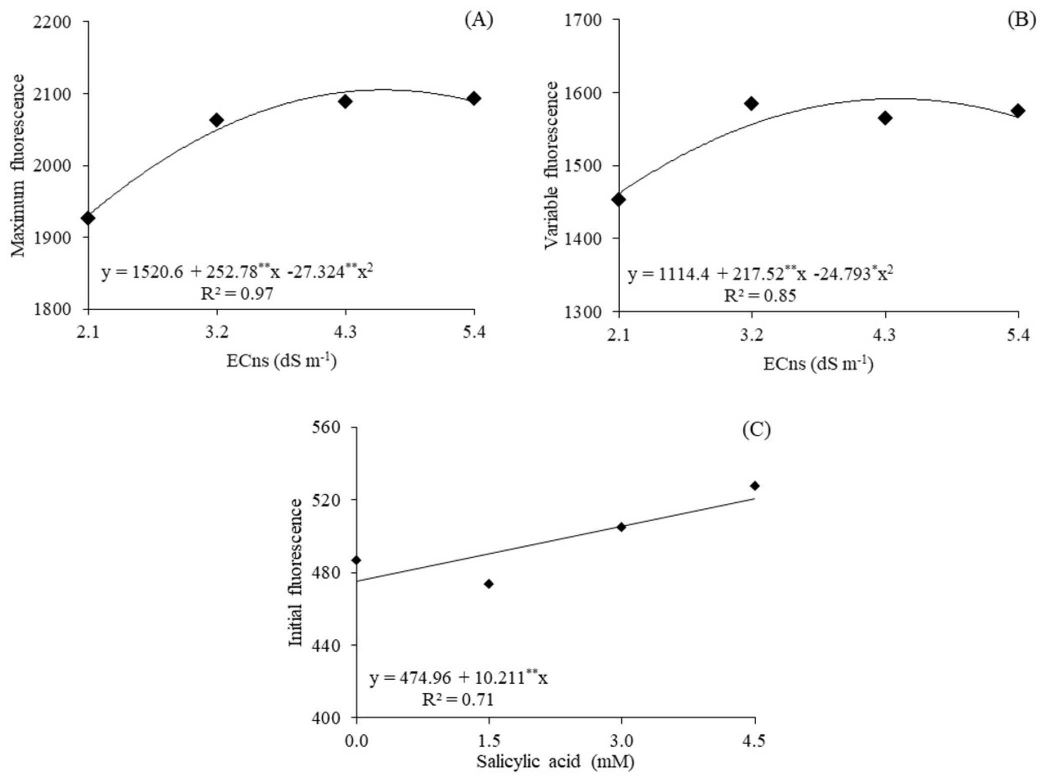


Figure 4. Maximum fluorescence (A) and variable fluorescence (B) of 'Gaúcho' melon plants as a function of the salinity of the nutrient solution – ECns and initial fluorescence (C) as a function of salicylic acid concentration, in hydroponic cultivation, 57 days after transplanting.

Table 4. Summary of the analysis of variance for the number of leaves (NL), stem diameter (SD), main branch length (MBL), dry mass of root (RDM), leaves (LDM), and stem (SDM), and root/shoot ratio (R/S) of 'Gaúcho' melon plants cultivated under nutrient solution salinity (ECns) and foliar application of salicylic acid (SA) in a hydroponic system, 67 days after transplanting.

Sources of variation	DF	Mean squares						R/S
		NL	SD	MBL	RDM	LDM	SDM	
Nutrient solution salinity (ECns)	3	59.95^{ns}	11.46**	3835.81**	15.03**	1212.30**	474.77**	0.0222**
Linear Regression	1	176.41^{ns}	30.74**	11116.87**	31.34**	2693.74**	36.455**	0.0627**
Quadratic Regression	1	2.34^{ns}	3.60*	315.37^{ns}	11.55*	0.68^{ns}	0.57^{ns}	0.0003^{ns}
Residual 1	15	20.21	0.69	213.18	3.49	128.96	27.36	0.0013
Salicylic acid (SA)	3	63.28^{ns}	1.33^{ns}	474.48*	1.03^{ns}	242.44^{ns}	85.14^{ns}	0.0029^{ns}
Linear Regression	1	59.50^{ns}	0.01^{ns}	1074.00*	0.06^{ns}	456.10^{ns}	125.11^{ns}	0.0012^{ns}
Quadratic Regression	1	23.01^{ns}	1.58^{ns}	117.04^{ns}	2.84^{ns}	204.10^{ns}	130.29^{ns}	0.0071^{ns}
Residual 2	60	26.76	0.60	159.71	2.18	89.47	40.68	0.0023
Interaction (ECns × SA)	9	11.05^{ns}	0.89^{ns}	160.11^{ns}	6.74**	94.09^{ns}	56.52^{ns}	0.0009^{ns}
CV 1 (%)		13.18	10.36	6.49	25.95	28.22	27.69	26.03
CV 2 (%)		15.16	9.65	5.62	20.50	23.51	33.77	35.08

CV = coefficient of variation. DF- degree of freedom. ^{ns} = not significant. * = significant at $p \leq 0.05$. **,= significant at ≤ 0.01.

(2.1 dS m^{-1}). From this salinity level, there was a decrease in SD, reaching the lowest value (7.44 mm) in plants subjected to ECns of 5.4 dS m^{-1}. The main branch length decreased linearly by 3.39% per unit increment in the electrical conductivity of the nutrient solution (Figure 5B). When comparing the MBL of plants grown under the lowest salinity of the solution (2.1 dS m^{-1}) to those that received ECns of 5.4 dS m^{-1}, an increase of 28.87 cm was observed in MBL.

Foliar application of salicylic acid at a concentration of 4.5 mM in 'Gaúcho' melon plants promoted higher growth in the main branch, with an increase of 1.36% for every 1.5 mM increase in SA concentration (Figure 5C).

The dry mass of leaves (Figure 6A) and stem (Figure 6B) were also negatively affected by the increase in salinity of the nutrient solution, with reductions of 7.63 and 10.14% per unit increase in nutrient solution salinity, respectively. When comparing the LDM and SDM of plants subjected to the highest level of ECns (5.4 dS m^{-1}) to those of plants grown under nutrient solution salinity of 2.1 dS m^{-1}, there were reductions of 14.19 and 10.20 g per plant, respectively.

The root/shoot ratio of 'Gaúcho' melon plants increased linearly as a function of the increase in nutrient solution salinity (Figure 6C), with an increment of 3.14% per unit increase in ECns. When comparing the R/S ratio of plants grown under ECns of 5.4 dS m^{-1} to that of plants that received the lowest salinity level of the nutrient solution (2.1 dS m^{-1}), an increase of 0.06 g g^{-1} was observed.

The interaction between the salinity levels of the nutrient solution and salicylic acid concentrations also significantly influenced the accumulation of root dry mass (Figure 7), and the maximum estimated value (8.49 g per plant) was obtained in plants subjected to ECns of 2.1 dS m^{-1} and SA concentration of 3.0 mM. Conversely, the lowest accumulation of root dry mass (6.26 g per plant) was obtained at the highest level of nutrient solution salinity (ECns=5.4 dS m^{-1}) and SA concentration of 4.5 mM.

4. Discussion

The use of water with high salinity has been widely studied in arid and semi-arid regions. The harmful effects on the physiology and morphology of most glycophyte crops such as the 'Gaúcho' melon plant, in traditional cultivation begins with the accumulation of salts in the soil, hindering the absorption of water and nutrients by the roots with subsequent nutritional imbalance aggravated by the excessive absorption of specific ions, causing changes in osmotic and ionic homeostasis, reflecting in limitations in photosynthetic activity (Dantas et al., 2021; Lacerda et al., 2022; Silva et al., 2022; Pinheiro et al., 2022a).

In a hydroponic system, the matric potential of the soil is negligible, with the osmotic potential being the main limiting factor for the absorption of water and nutrients by plants (Leal et al., 2020), which explains the smaller reductions observed in the transpiration flow of melon plants in the present study, which showed losses of the order of 20 and 18% for stomatal conductance and transpiration even under the application of an ECw of 5.4 dS m^{-1}. Unlike the limitations that occur in conventional cultivation using soil, as observed by Silva et al. (2021b), when evaluating melon cultivars and accessions under irrigation with 0.5 and 4.5 dS m^{-1} water, found reductions that reached 41.79% in *gs* and 30.77% in *E*.

Similarly, the internal carbon concentration showed consistent decreases with that observed for stomatal opening due to the increase in saline level, which is

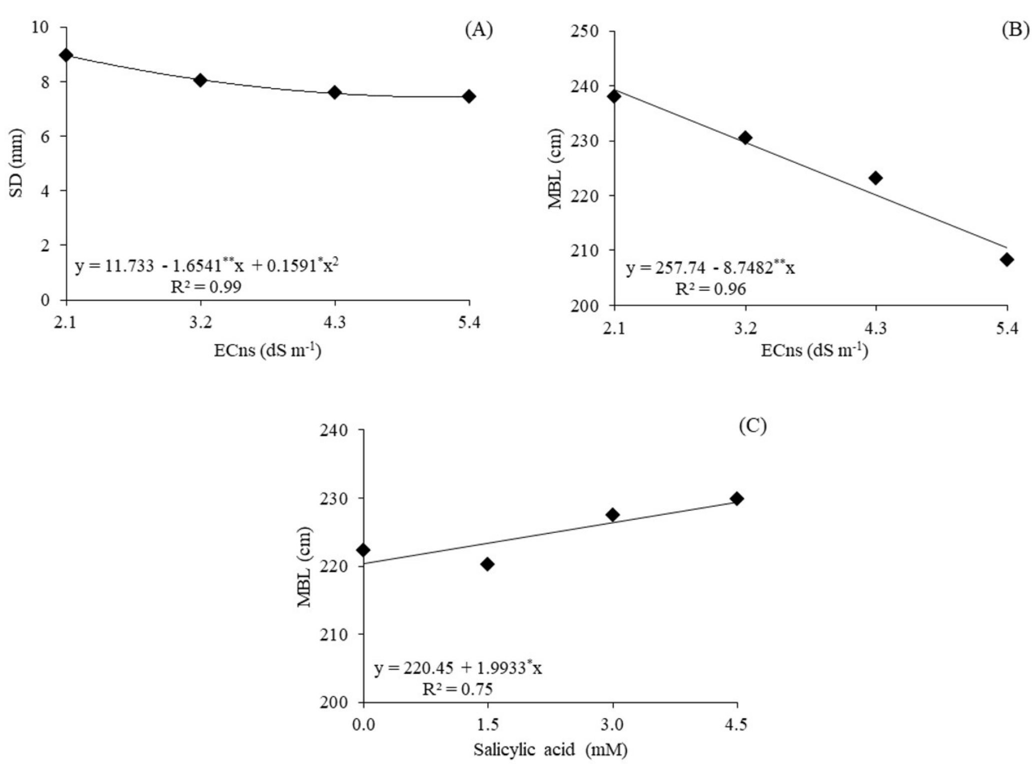


Figure 5. Stem diameter - SD (A) and main branch length - MBL (B) of 'Gaúcho' melon plants, as a function of the salinity level of the nutrient solution - ECns and MBL (C) as a function of salicylic acid concentration, in hydroponic cultivation, 67 days after transplantation.

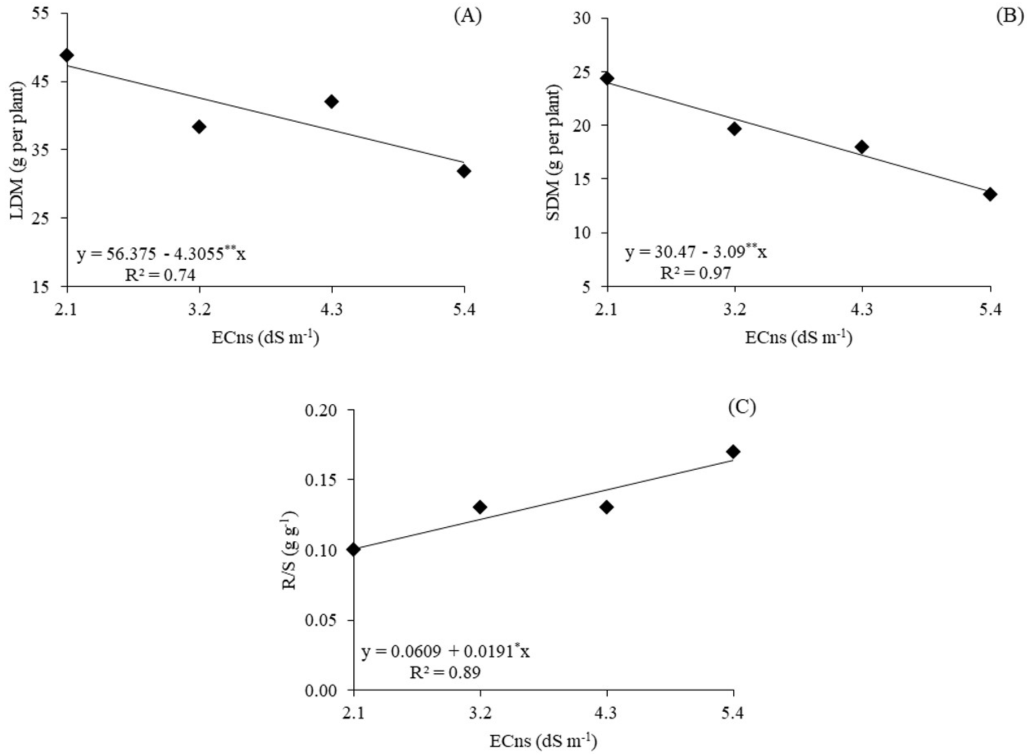
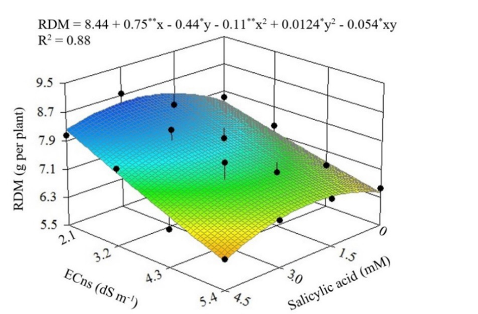


Figure 6. Dry mass of leaves - LDM (A), stem - SDM (B), and root/shoot ratio - R/S (C) of 'Gaúcho' melon plants, as a function of the salinity level of the nutrient solution - ECns, in the hydroponic cultivation, 67 days after transplanting.

correlated to the fact that the entry of carbon into the substomatic chamber occurs through gas exchange between the stomata of the plant and the environment (Silva et al., 2021a). In this way, the reduction in the CO_2 assimilation rate of the melon plants caused by the increase in the salinity of the nutrient solution can be attributed to the reduction of carbon in the biochemical phase, changing the proportion of Ribulose-1,5-bisphosphate carboxylase activity to oxygenase, which interferes with carbon fixation (Busch, 2020; Ghassemi-Golezani and Farhadi, 2022).

On the other hand, the photochemical efficiency of melon was increased with the increase in salinity of the nutrient solution, and the observed increases in variable and maximum fluorescence were an indicator that the excess of salts did not interfere with the active potential energy of the photosystem II (PSII), thus regulating the reaction centers in the quinone photoreduction activity and in the transfer of electrons between the photosystems, which enables the transfer of energy for the formation of NADPH and ATP to be used in the Calvin cycle (Huang et al., 2019).

The application of salicylic acid has been associated with stomatal regulation and maintenance of photosynthetic activity in plants under saline stress (Silva et al., 2021a; Ghassemi-Golezani and Farhadi, 2022; Dehnavi et al., 2022). However, in the present research, the application of salicylic acid reduced the internal concentration of CO_2 and the rate of carbon assimilation of the melon plants, being aggravated by the increase in the salinity level of the nutrient solution. A situation that can be associated



X and Y correspond to ECns and salicylic acid concentrations, respectively.

Figure 7. Root dry mass of 'Gaúcho' melon plants, as a function of the interaction between the salinity level of the nutrient solution - ECns and foliar application of salicylic acid - SA, in the hydroponic cultivation, 67 days after transplanting.

with the concentration evaluated during the experiment (1.5 to 4.5 mM), considered high when it exceeds 1 mM (Koo et al., 2020). Jayakannan et al. (2015) highlight that the application of high concentrations of salicylic acid induces stomatal closure and reduces the activity of the enzymes catalase and ascorbate peroxidase, leading to an increase in the concentration of H_2O_2, which causes damage to photosynthetic activity by increasing the generation of reactive species of oxygen.

This situation corroborates the initial fluorescence values of melon plants under salicylic acid application, as it is the minimum energy required to initiate the photochemical process. An increase in this variable, results in damage to the photosystem activity, reducing the efficiency in transporting excitation energy from the antenna to the reaction centers (Feyziyev, 2019). Damage to photochemical activity by the application of a high concentration of salicylic acid was found in the research of Habibi and Vaziri (2017) with barley (*Hordeum vulgare* L.) and Poór et al. (2019) on tomato (*Solanum lycopersicum* L. cv. Ailsa Craig).

The melon growth was negatively affected by the increase in salinity of the nutrient solution, with the observed declines in stem diameter and main branch length consistent with the decrease in gas exchange. In this case, the reduction in the stomatal opening, observed by stomatal conductance, may have caused less water transport in the xylem vessels, which affects cell turgor, decreasing shoot expansion (Jerszurki et al., 2020). In the same proportion, the meristematic activity of the main branch tends to be affected by the reduction in carbon fixation in the photosynthetic process, thus restricting growth to restore the water potential of the plant (Giordano et al., 2021).

However, this process causes a greater release of energy for the production of osmolytes that can stabilize the entry of water and avoid the excessive accumulation of toxic ions, which limits the production of phytomass in the shoot to increase the root area of the plant under stress (Giordano et al., 2021; Silva et al., 2021b). This behavior was observed in the present research, in which the increase in the salinity of the nutrient solution resulted in a reduction in the dry biomass of leaves and stem, being higher than that observed for the dry phytomass of the root, resulting in an increase in the root/shoot ratio of the plants of melon. In a hydroponic system, similar responses to the salinity of the solution were reported in grapevine (*Vitis vinifera* L.) cultivars by Fozouni et al. (2012) and in the cultivation of mini watermelon (*Citrullus lanatus* L.) by Silva et al. (2022).

The application of salicylic acid resulted in an increase in the length of the main branch of melon plants, probably due to the hormonal action of this substance, which increases the production of metabolites such as proline, betaine glycine, and carbohydrates to improve water regulation of the plant, with less energy release for root growth and, therefore, for the greater meristematic activity of the plant (Ghassemi-Golezani and Farhadi, 2022). This fact justifies the linear reduction that occurred in the dry mass of roots by the application of salicylic acid in all saline levels of the nutrient solution. However, the application of salicylic acid did not show any effect on the other variables of melon growth, which can be explained by its positive action in the production of secondary metabolites being impaired in the limitation of antioxidant activity, due to the synergy of the application of high concentrations with the production of H_2O_2 (Jayakannan et al., 2015; Poór et al., 2019; Koo et al., 2020).

5. Conclusions

Nutrient solution of electrical conductivity of 4.3 and 5.4 dS m^{-1} promotes higher maximum and variable fluorescence, respectively. The stomatal conductance, transpiration, stem diameter, main branch length, leaf dry mass, and stem dry mass of 'Gaúcho' melon plants decrease with an increase in salinity of the nutrient solution. Salicylic acid increases the initial fluorescence and the main branch length of 'Gaúcho' melon plants in hydroponic cultivation. Salicylic acid at a concentration of 1.5 to 4.5 mM did not attenuate the effects of salt stress on the internal CO_2 concentration, CO_2 assimilation rate, and root dry mass of 'Gaúcho' melon plants.

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