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Original Article

Salicylic acid does not mitigate salt stress on the morphophysiology and production of hydroponic melon

Ácido salicílico não mitiga o estresse salino sobre a morfofisiologia e produção de meloeiro hidropônico

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Abstract

The excess of salts present in the water can limit the hydroponic cultivation of melon in semi-arid regions of the Brazilian Northeast, making it necessary to use strategies that allow the use of these waters. Among these strategies, the use of elicitor substances stands out, such as salicylic acid. In this context, this study aimed to evaluate the effect of foliar application of salicylic acid in mitigating the harmful effects of salt stress on the morphophysiology and production of 'Gaúcho' melon cultivated in a hydroponic system. A completely randomized design was adopted in a split-plot scheme, with four levels of electrical conductivity of the nutrient solution - ECsn (2.1, 3.2, 4.3, and 5.4 dS m^{-1}) considered the plots and four salicylic acid concentrations - SA (0, 1.5, 3.0, and 4.5 mM), the subplots, with six replications. The foliar application of salicylic acid concentrations did not mitigate the deleterious effects of salt stress on the morphophysiology and yield of melon grown in hydroponic system. The concentration of 4.5 mM of salicylic acid intensified the harmful effects of the salinity of the nutrient solution on gas exchange and fresh weight of hydroponic melon.

Keywords: *Cucumis melo* L., salinity, phytohormone.

Resumo

O excesso de sais presentes na água pode limitar o cultivo hidropônico do meloeiro em regiões semiáridas do Nordeste brasileiro, fazendo-se necessária a utilização de estratégias que possibilitem o uso dessas águas, dentre essas estratégias, destaca-se a utilização de substâncias elicitoras, como ácido salicílico. Neste contexto, objetivou-se avaliar o efeito da aplicação foliar de concentrações de ácido salicílico na mitigação dos efeitos deletérios do estresse salino a morfofisiologia e produção do meloeiro 'Gaúcho' cultivado em sistema hidropônico. O experimento foi desenvolvido em casa de vegetação na Universidade Federal de Campina Grande, Pombal-PB. Adotou-se o delineamento inteiramente casualizado em esquema de parcelas subdivididas, sendo quatro níveis de condutividade elétrica da solução nutritiva - CEsn (2,1; 3,2; 4,3 e 5,4 dS m^{-1}) considerados as parcelas e quatro concentrações de ácido salicílico - AS (0, 1,5; 3,0 e 4,5 mM), as subparcelas, com seis repetições. A aplicação foliar das concentrações de ácido salicílico não mitigaram os efeitos deletérios do estresse salino sobre a morfofisiologia e produção do meloeiro cultivado em sistema hidropônico. A concentração de 4,5 mM de ácido salicílico intensificou os efeitos deletérios da salinidade da solução nutritiva sobre as trocas gasosas e peso fresco de fruto do meloeiro hidropônico.

Palavras-chave: *Cucumis melo* L., salinidade, fitohormônio.

1. Introduction

Melon (*Cucumis melo* L.) is one of the most popular cucurbits in the world, and its production has increased considerably in recent decades. In 2019, Brazil had planted an area of 22.27 million hectares, resulting in the production of 587.69 million tons, with an important economic and social role, mainly for the Northeast region, responsible for 95.86% of Brazilian melon production in the states of Rio Grande do Norte, Ceará, Bahia and Pernambuco (IBGE, 2021).

Although the semi-arid region of the Northeast has potential for melon production and commercialization, the quantitative and qualitative limitation of water can restrict its production, which is due to the poor distribution and limitation of rainfall, in addition to high temperatures and low relative humidity, resulting in water scarcity and accumulation of salts in the water sources of this region (Nobre et al., 2012; Lima et al., 2016; Silva et al., 2022).

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However, irrigation with saline water can cause the accumulation of soluble salts in the soil, which compromises the absorption of water and nutrients by the plant, due to the reduction of the osmotic potential of water in the soil. In addition, the accumulation of ions, mainly Na^+ and Cl^-, can cause specific toxicity and nutritional imbalance, resulting in low vegetative growth and, consequently, lower production (Bonifácio et al., 2018; Capitulino et al., 2022).

Some management strategies can enable the use of saline water in irrigation, among which hydroponic cultivation stands out, as it consists of soilless cultivation, in which the roots of plants are submerged in a liquid medium and receive a nutrient solution composed of nutrients essential for plant development (Soares et al., 2015; Silva et al., 2018; Dantas et al., 2021). This method benefits the producer and the environment, providing products with longer shelf life, promoting shorter time for harvesting, optimizing water consumption and labor reduction (Paulus et al., 2012).

In addition to hydroponic cultivation, the induction of defense mechanisms aimed at plant tolerance to stress can enable the use of saline water in irrigation, through the application of compounds (natural or synthetic) such as salicylic acid (SA), which, when previously applied at low concentrations, can lead to a greater tolerance to stress and be effectively used as an eliciting agent (Silva et al., 2020a). This plant hormone plays several physiological roles in plants, including floral induction, nutrient absorption, ethylene biosynthesis, stomatal closure and photosynthesis, besides increasing the activity of antioxidant enzymes such as peroxidases, superoxide dismutase and catalase (Ma et al., 2017; Silva et al., 2020a).

In view of the above, the objective of the present study was to evaluate the effect of foliar application of salicylic acid in mitigating the deleterious effects of saline stress on gas exchange, the accumulation of phytomass, and the production of 'Gaúcho' melon cultivated in hydroponic.

2. Material and Methods

The experiment was conducted in a greenhouse between May and August 2021, at the Center for Science and Agri-Food Technology (CCTA) of the Federal University of Campina Grande (UFCG), in Pombal, PB, Brazil, at the geographic coordinates: 6°46'13" South latitude and 37°48'6" West longitude, at an average altitude of 184 m. The data of temperature (maximum and minimum) and mean relative humidity of air observed during the experimental period at the experimental site are shown in Figure 1.

A completely randomized design was adopted in a split-plot scheme, with four levels of electrical conductivity of the nutrient solution - ECsn (2.1, 3.2, 4.3, and 5.4 dS m^{-1}) considered the plots and four salicylic acid concentrations - SA (0, 1.5, 3.0, and 4.5 mM), the subplots, with six replications, making a total of 96 plants. Due to the absence of research with salicylic acid in melon crop, the concentrations tested were established based on the study conducted by Silva et al. (2020a) with the soursop crop

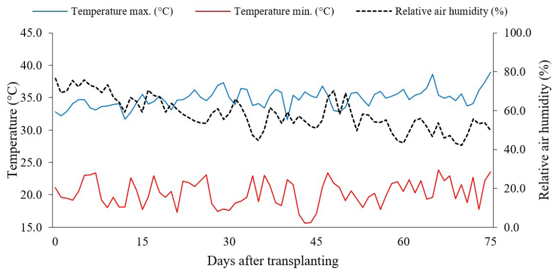

Figure 1. Air temperature (maximum and minimum) and mean relative air humidity inside the greenhouse during the experimental period.

(*Annona muricata* L.). The electrical conductivity levels of the nutrient solution were based on the study conducted by Dantas et al. (2021), with zucchini (*Cucurbita pepo*).

The hydroponic system used was NFT (Nutrient Film Technique) type, made with 100-mm-diameter, 6-m-long polyvinyl chloride (PVC) pipe, comprised four subsystems spaced 0.80 m apart, and each subsystem contained three channels spaced 0.40 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 with a 4% slope for the nutrient solution to flow. At the lowest part of each bench of the hydroponic system, a 150-L polyethylene reservoir was placed to collect and conduct the nutrient solution to the channels. The nutrient solution was pumped to the channels by a 35-W pump, at a flow rate of 3 L min^{-1}.

Sowing was carried out in 50-mL disposable cups, containing washed coconut fiber as substrate, using the melon cultivar 'Gaúcho', for being a rustic plant, well accepted by the producers, because it adapts to high temperatures, has a prostrate growth habit, and produces fruits with the pulp of excellent aroma and flavor, which can weigh between 1.0 and 2.5 kg. After the appearance of the second pair of true leaves, the seedlings were transplanted to the structure and trained vertically by staking, leaving only the main branch and a branch with the fruit. The plants were trained vertically and, when necessary, phytosanitary treatments were performed. The flowers were artificially pollinated and a brush was used to transfer pollen grains from anthers to the stigma of different plants.

After fertilization of the flower, the number of fruits was controlled, leaving only one per plant. Limiting the number of fruits per plant was performed as suggested by Silva et al. (2020b) in the vertical cultivation of mini watermelon (*Citrullus lanatus* L.), to improve fruit quality and increase fruit production.

From the germination stage until the emergence of the first true leaves, plants received half strength (50% concentration) nutrient solution recommended by Hoagland and Arnon (1950), prepared with local-supply water (0.3 dS m^{-1}) whose chemical composition of nutrients (Table 1) resulted in a solution with electrical conductivity of 2.1 dS m^{-1}, which was used until the beginning of the differentiation of salinity levels (15 DAT).

Table 1. Chemical composition of nutrients present in the general nutrient solution indicated by Hoagland and Arnon (1950), used in hydroponic cultivation of 'Gaúcho' melon.

Elements	mg L^{-1} Nutrient solution	Fertilizers	g L^{-1} Nutrient solution
N	210	KNO_3	101.10
P	31	KH_2PO_4	136.09
K	234	$Ca(NO_3).4H_2O$	236.15
Ca	200	$MgSO_4.7H_2O$	246.49
Mg	48	H_3BO_3	3.10
S	64	$MnSO_4.4H_2O$	1.70
B	0.5	$ZnSO_4.7H_2O$	0.22
Mn	0.5	$CuSO_4.5H_2O$	0.75
Zn	0.05	$(NH_4)_6Mo7O_{24}.4H_2O$	1.25
Cu	0.02	$FeSO_4$	13.9
Mo	0.01	EDTA - Na	13.9
Fe	5		
Na	1.2		
Cl	0.65		

The saline solutions used in the cultivation were obtained by adding sodium (NaCl), calcium ($CaCl_2.2H_2O$), and magnesium chloride ($MgCl_2.6H_2O$) salts in the equivalent proportion of 7:2:1, respectively. This is the proportion of Na^+, Ca^{2+}, and Mg^{2+} commonly found in the waters used for irrigation in the semi-arid region of northeastern Brazil. The solutions were prepared in the laboratory considering the relationship between ECw and the concentration of salts (Richards, 1954), according to Equation 1:

$$Q = 640 \times ECw \quad (1)$$

where: Q = Quantity of salts to be applied (mg L^{-1}); ECw = Electrical conductivity of water (dS m^{-1}).

Nutrient solution circulation was controlled by digital timers programmed to turn on the system for 15 min. and turn it off for 15 min., from 06:00 to 18:00 h; in the nighttime the nutrient solution circulated for 15 min. on and 1 h off. Nutrient solution management was carried out using a closed system, i.e., the solution went through the whole system, of a specific treatment, and returned to the specific reservoir of this treatment, promoting recirculation. The values of ECns, pHns and the volume consumed in each sub-system were monitored every day in the late afternoon.

Salicylic acid solutions were prepared according to concentration through the dissolution of salicylic acid (SA) in 30% ethyl alcohol. Applications of salicylic acid started 10 days after transplanting (DAT) and 72 hours before the start of the application of the saline nutrient solution. Subsequently, four applications were performed after 17:00 h with a 15-day interval, by foliar spraying, completely wetting the leaves (abaxial and adaxial sides), using a manual sprayer. Plastic curtains were used to prevent the acid from drifting onto plants of other treatments.

At 56 days after transplanting (DAT), gas exchange was analyzed by determining the CO_2 assimilation rate - *A* (μmol CO_2 m^{-2} s^{-1}), transpiration - *E* (mmol H_2O m^{-2} s^{-1}), stomatal conductance - *gs* (mol H_2O m^{-2} s^{-1}), and intercellular CO_2 concentration – *Ci* (μmol CO_2 m^{-2} s^{-1}), in the third leaf counted from the apex. These data were then used to calculate water use efficiency (*WUEi*) (*A/E*) [(μmol m^{-2} s^{-1}) (mol H_2O m^{-2} s^{-1})$^{-1}$] and instantaneous carboxylation efficiency (*CEi*) [(μmol m^{-2} s^{-1}) (μmol mol^{-1})]$^{-1}$, using the portable photosynthesis meter 'LCPro+' from ADC BioScientific Ltda. Readings were performed between 6:00 and 10:00 a.m., on the third fully expanded leaf, under natural conditions of air temperature and CO_2 concentration, and using an artificial radiation source of 1,200 μmol fótons m^{-2} s^{-1}, established through the curve of photosynthetic response to light, determining the point of photosynthetic saturation by light.

At the same time, the percentage of intercellular electrolyte leakage was determined in order to evaluate the cell membrane rupture capacity under salt stress conditions. For this, 10 leaf discs with 113 mm^2 area were collected from the 3rd leaf of the stem apex, washed with distilled water and placed in beakers, which contained 50 mL of distilled water, and were hermetically sealed with aluminum foil. The beakers were kept at 25 ºC for 24 horas and immediately after, the initial electrical conductivity (Ci) was measured. Subsequently, the beakers were taken to an oven with forced air ventilation and subjected to a temperature of 80 ºC for 120 minutes, and the final electrical conductivity (Cf) was measured. The percentage of intercellular electrolyte leakage was obtained according to Scotti-Campos et al. (2013), as shown in Equation 2.

$$IEL = \frac{Ci}{Cf} \times 100 \quad (2)$$

where: IEL = intercellular electrolyte leakage (%); Ci = initial electrical conductivity (dS m^{-1}); and Cf = final electrical conductivity (dS m^{-1}).

At the end of the crop cycle, 74 days after transplanting (DAT), the plants were collected, separated into leaves, stems, and roots, placed in paper bags, and dried in an air circulation oven, maintained at 65 ºC, until constant weight. Subsequently, the material was weighed on a precision scale to obtain the biomass of leaves, stems, and roots, and then shoot dry biomass (SDB) and total dry biomass (TDB) were obtained by summation.

Fruit harvesting began when the fruits showed a yellow and uniform color. After fruit harvest, the polar diameter (PD) and equatorial diameter (ED) of the fruits, soluble solids (SS), and fresh fruit weight (FFW) were determined. The polar and equatorial diameters of the fruits were determined by a millimeter tape measure and the results were expressed in cm. Soluble solids were obtained using a digital refractometer (Digital Refractometer, USA).

The data were analyzed for normality (Shapiro-Wilk test) and subsequently subjected to analysis of variance by the F test ($p \leq 0.05$). When significant, polynomial regression analysis (linear and quadratic) was performed for the nutrient solution electrical conductivity levels and salicylic acid concentrations, using the statistical program SISVAR (Ferreira, 2019). In the case of the significance of the interaction between factors, TableCurve 3D software was used to prepare the response surfaces.

3. Results and Discussion

There was a significant effect of the nutrient solution electrical conductivity levels on stomatal conductance (*gs*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), and transpiration (*E*) of 'Gaúcho' melon (Table 2). Salicylic acid concentrations significantly influenced only stomatal conductance. The interaction between the factors (ECns × SA) significantly influenced *gs*, *A*, *Ci,* and *E* of 'Gaúcho' melon plants.

For stomatal conductance (Figure 2A), plants grown under ECns of 2.1 dS m^{-1} and without foliar application of salicylic acid (0 mM) stood out with a maximum value of 0.549 mol H_2O m^{-2} s^{-1}. However, the salicylic acid concentration of 4.5 mM and ECns of 5.4 dS m^{-1} resulted in a lower value of *gs* (0.243 mol H_2O m^{-2} s^{-1}). When comparing the plants subjected to ECns of 5.4 dS m^{-1} to those that received the lowest level of electrical conductivity of the nutrient solution, a reduction of 0.307 mol H_2O m^{-2} s^{-1} was observed. Generally, plants under salt stress conditions

Table 2. Summary of the analysis of variance for stomatal conductance (*gs*), CO_2 assimilation rate (*A*), internal CO_2 concentration (*Ci*), transpiration (*E*), instantaneous water use efficiency (*WUEi*), and instantaneous carboxylation efficiency (*CEi*) of 'Gaúcho' melon, cultivated in hydroponic system with different levels of electrical conductivity of the nutrient solution (ECns) and foliar application of salicylic acid (SA), 56 days after transplanting.

Source of variation	DF	Mean squares					
		gs	*A*	*Ci*	*E*	*WUEi*	*CEi*
ECns	3	0.08**	77.50**	4,868.77**	1.46*	0.83ns	0.0001ns
Linear Regression	1z	0.19**	220.89**	14,476.03**	4.14**	1.81ns	0.0003ns
Quadratic Regression	1	0.06**	10.19ns	104.16ns	0.07ns	0.45ns	0.0008ns
Residual 1	15	0.003	8.34	651.43	0.37	0.56	0.0002
SA	3	0.05**	3.99ns	2,400.27ns	0.74ns	1.12ns	0.0005ns
Linear Regression	1	0.09**	11.53ns	5,852.03ns	0.83ns	2.35ns	0.001ns
Quadratic Regression	1	0.01*	0.11ns	170.66ns	0.31ns	0.44ns	0.000009ns
Interaction (ECns × SA)	9	0.021**	20.9*	3,461.94**	1.04**	1.23ns	0.0005ns
Residual 2	65	0.004	10.02	988.12	0.49	0.48	0.0003
CV 1 (%)		15.59	15.73	10.66	13.07	19.01	18.77
CV 2 (%)		17.40	17.24	13.12	14.79	17.55	23.42

DF: Degrees of freedom; CV: Coefficient of variation; *, ** and ns significant at 0.05 and 0.01 probability levels and not significant.

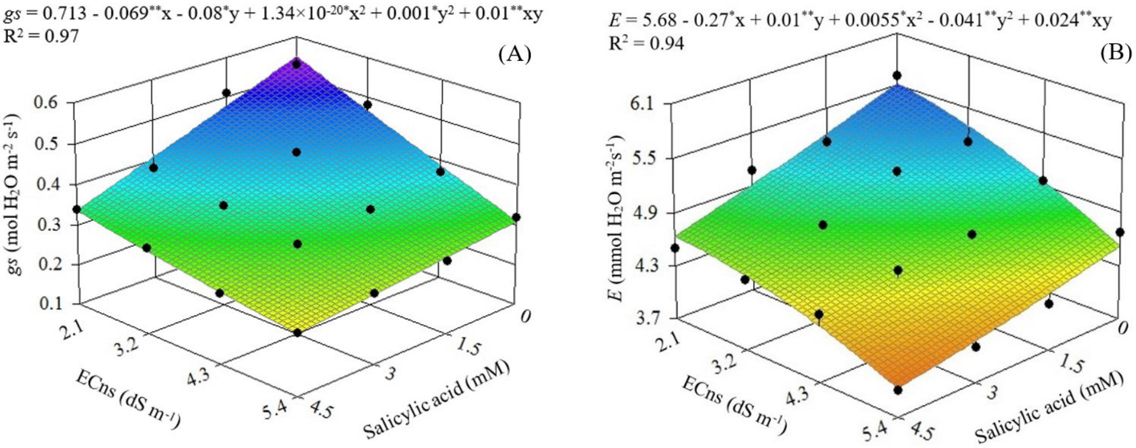

Figure 2. Stomatal conductance - *gs* (A) and transpiration - *E* (B) of 'Gaúcho' melon, as a function of the interaction between the levels of electrical conductivity of the nutrient solution - ECns and foliar application of salicylic acid, 56 days after transplanting. X and Y correspond to ECns and salicylic acid concentrations, respectively. * and ** represent significance at 0.05 and 0.01 probability levels, respectively.

close their stomata as a defense mechanism, aiming at reducing the loss of water to the atmosphere and reducing the absorption of toxic ions (Lima et al., 2019). Veloso et al. (2021), evaluating the osmoprotective capacity of salicylic acid on 'All Big' bell pepper plants irrigated with waters of different salinity levels, found that the highest value of *gs* (0.27 mol H_2O m^{-2} s^{-1}) was obtained in plants subjected to SA concentration of 1.5 mM, with reductions from this concentration.

'Gaúcho' melon plants (Figure 2B) subjected to nutrient solution electrical conductivity of 2.1 dS m^{-1} and without application of salicylic acid (0 mM) obtained the highest leaf transpiration (5.52 mmol H_2O m^{-2} s^{-1}). ECns of 5.4 dS m^{-1} associated with foliar application of salicylic acid at a concentration of 4.5 mM caused a decrease in the transpiration of melon plants. Reduction in transpiration reflects partial closure of the stomata, as previously observed (Figure 2A), and can be attributed to the decrease in the potential energy of water in the roots and/or transport of abscisic acid to the leaves, resulting in an increase in stomatal resistance and decrease in carbon concentration in the substomatal chamber (Liu et al., 2015). Dantas et al. (2021), studying the effects of nutrient solution salinity (ECns between 2.1 and 5.1 dS m^{-1}), found that leaf transpiration of Italian zucchini plants decreased linearly with the increase of ECns levels from 2.1 dS m^{-1}.

For the internal CO_2 concentration (Figure 3A), plants grown without application of salicylic acid obtained the highest value (290.8 µmol CO_2 m^{-2} s^{-1}) when associated with the lowest level of ECns (2.1 dS m^{-1}). On the other hand, plants grown under no foliar application of salicylic acid and with ECns of 5.4 dS m^{-1} stood out with the lowest *Ci* value (208.0 µmol CO_2 m^{-2} s^{-1}). When comparing plants that received ECns of 5.4 dS m^{-1} to those that received 2.1 dS m^{-1} in the absence of salicylic acid, a decrease in *Ci* of 28.49% was observed. The reduction in *Ci* associated with the decrease in stomatal conductance in melon plants under the highest ECns can be attributed not only to stomatal closure that restricts CO_2 diffusion in the substomatal chamber (Lima et al., 2020a) but also to impaired activity of ribulose-1,5-bisphosphate carboxylase oxygenase, which predisposes the photosynthetic apparatus to increased energy dissipation and negative regulation of photosynthesis when plants are subjected to salt stress (Silva et al., 2018). Melo et al. (2017), in a study with bell pepper evaluating gas exchange and photosynthetic pigment contents as a function of irrigation with saline waters (ECw: 0, 1, 3, 5, 7, and 9 dS m^{-1}), obtained a maximum value of 229.80 µmol CO_2 m^{-2} s^{-1} for the internal CO_2 concentration in plants irrigated with ECw of 3.0 dS m^{-1}.

The CO_2 assimilation rate of 'Gaúcho' melon (Figure 3B) was also affected by the interaction between the factors (ECns × SA). The CO_2 assimilation rate decreased when plants were cultivated with the highest level of ECns (5.4 dS m^{-1}) and salicylic acid concentration of 4.5 mM, obtaining a minimum value of 14.33 µmol CO_2 m^{-2} s^{-1}. However, the highest *A* (21.50 µmol CO_2 m^{-2} s^{-1}) was obtained in melon plants subjected to a concentration of 1.3 mM salicylic acid and cultivated with ECns of 2.1 dS m^{-1}, corresponding to an increase in *A* of 2.53% (0.544 µmol CO_2 m^{-2} s^{-1}) compared to plants that did not receive the foliar application of salicylic acid (0 mM - Control) and were under ECns of 2.1 dS m^{-1}. The reduction in CO_2 assimilation rate in plants grown under ECns of 5.4 dS m^{-1} occurred due to stomatal closure under salt stress, as a strategy to reduce the flow of water vapor and CO_2 diffusion in the cells of the leaf mesophyll, compromising transpiration and CO_2 assimilation rate (Altuntas et al., 2018; Dias et al., 2019).

Soares et al. (2021) also found that an increase in electrical conductivity negatively affected the CO_2 assimilation rate of pomegranate seedlings, with a reduction of 21.04% between salinity levels of 0.3 and 6.3 dS m^{-1}. However, the positive effect of the application of 1.3 mM salicylic acid on plants grown under the lowest level of ECns may be related to the capacity of salicylic acid to improve enzymatic and photosynthetic activities,

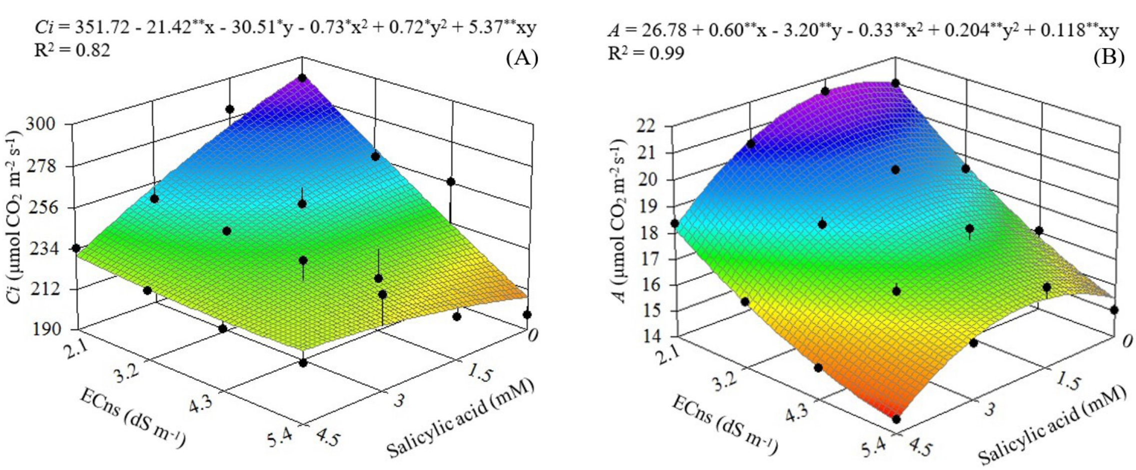

Figure 3. Internal CO_2 concentration - *Ci* (A) and CO_2 assimilation rate - *A* (B) of 'Gaúcho' melon, as a function of the interaction between the levels of electrical conductivity of the nutrient solution - ECns and foliar application of salicylic acid, 56 days after transplanting. X and Y correspond to ECns and salicylic acid concentrations, respectively. * and ** represent significance at 0.05 and 0.01 probability levels, respectively.

maintaining the balance between the production and elimination of reactive oxygen species (Batista et al., 2019). Silva et al. (2020a), in a study with the soursop cv. 'Morada Nova' under irrigation with saline water (ECw ranging from 0.8 to 4.0 dS m^{-1}) and foliar application of salicylic acid (concentration up to 3.6 mM), concluded that the exogenous application of salicylic acid also induced improvements in the CO_2 assimilation rate.

The levels of electrical conductivity of the nutrient solution (ECns) had significant effects on intercellular electrolyte leakage (IEL), shoot dry biomass (SDB), and total dry biomass (TDB) of 'Gaúcho' melon plants (Table 3). Salicylic acid concentrations and the interaction between factors (ECns × SA) did not significantly influence any of the variables evaluated.

A unit increase in nutrient solution salinity caused a linear increase of 7.15% in the intercellular electrolyte leakage in the leaf blade of 'Gaúcho' melon (Figure 4A). When comparing the IEL of plants cultivated with ECns of 5.4 dS m^{-1} to that of plants under the lowest level of nutrient solution salinity, an increase of 20.52% was found. Due to the increase in nutrient solution salinity, there may be a nutritional imbalance, affecting the availability of Ca^{2+}, an essential element for cell wall formation (Ferraz et al., 2015; Hurtado-Salazar et al., 2017), favoring cell membrane rupture, with the release of ions, which leads to greater loss in integrity and destabilization of the cell membrane (Ataíde et al., 2012). Wanderley et al. (2020) cultivated passion fruit under irrigation with saline water (0.3, 1.0, 1.7, 2.4, and 3.1 dS m^{-1}) and found that the increase in electrical conductivity of water resulted in a 64.27% increase in electrolyte leakage in the leaf blade of plants subjected to irrigation with water of 3.1 dS m^{-1} compared to those under the lowest salinity level (0.3 dS m^{-1}).

The shoot dry biomass (SDB) and total dry biomass (TDB) of melon were also sharply reduced with the increase in ECns levels, decreasing by 8.47 and 7.74% per unit increase in ECns, respectively. When comparing plants subjected to ECns of 5.4 dS m^{-1} to those that received the lowest level of nutrient solution salinity (2.1 dS m^{-1}), reductions of 34.01 and 30.52% (24.65 and 24.44 g per plant) were found in SDB and TDB, respectively. Decreases in biomass accumulation occur due to osmotic and ionic effects, which reduce the availability of water to plants, causing a decrease in cell elongation, besides inducing stomatal closure and a decrease in CO_2 assimilation rate, photosynthetic efficiency, and consequently, plant growth (Lima et al., 2021). Araújo et al. (2016), evaluating the initial growth and tolerance of melon cultivars to water salinity (ECw 0.6 to 3.0 dS m^{-1}), verified a linear reduction of 12.2% in dry biomass accumulation with increasing salinity, regardless of the cultivar evaluated.

The nutrient solution electrical conductivity levels had a significant effect on fresh fruit weight (FFW), equatorial diameter (ED), polar diameter (PD), and soluble solids (SS) of 'Gaúcho' melon fruits. Salicylic acid concentrations did not significantly influence any of the evaluated variables in 'Gaúcho' melon plants (Table 4). However, the interaction between the factors (ECns × SA) significantly affected only fresh fruit weight and soluble solids.

For the fresh weight of melon fruits (Figure 5A), plants grown under nutrient solution salinity of 2.1 dS m^{-1} and without foliar application of salicylic acid (0 mM) stood out with the maximum estimated value of 1245.56 g per fruit. On the other hand, plants subjected to ECns of 5.4 dS m^{-1} and SA concentration of 4.5 mM obtained a minimum value of 751.24 g per fruit. In relative terms, there was a decrease in FFW of 494.32 g per fruit between plants that received ECns of 5.4 dS m^{-1} and SA concentration of 4.5 mM and plants that were under nutrient solution salinity of 2.1 dS m^{-1} and without foliar application of SA (0 mM).

The reduction in fresh fruit weight may be related to energy relocation due to the increase in salinity levels, resulting in decreased metabolic energy in plants

Table 3. Summary of the analysis of variance for intercellular electrolyte leakage (IEL), shoot dry biomass (SDB), and total dry biomass (TDB) of 'Gaúcho' melon cultivated in hydroponic system with different levels of electrical conductivity of nutrient solution (ECns) and exogenous application of salicylic acid (SA), 74 days after transplanting.

Source of variation	DF	Mean Squares		
		IEL	SDB	TDB
ECns	3	36.34**	3,016.50**	3,026.78**
Linear Regression	1	92.69**	8,107.71**	7,974.04**
Quadratic Regression	1	0.69^{ns}	525.00^{ns}	727.04^{ns}
Residual 1	15	3.58	199.51	244.98
SA	3	0.91^{ns}	276.61^{ns}	333.81^{ns}
Linear Regression	1	1.22^{ns}	732.50^{ns}	868.52^{ns}
Quadratic Regression	1	0.84^{ns}	0.69^{ns}	5.69^{ns}
Interaction (ECns × SA)	9	4.09^{ns}	195.26^{ns}	228.38^{ns}
Residual 2	65	2.39	225.27	246.05
CV 1 (%)		13.36	23.48	23.07
CV 2 (%)		10.92	24.95	23.12

DF: Degrees of freedom; CV: Coefficient of variation; *, ** and ^{ns} significant at 0.05 and 0.01 probability levels and not significant.

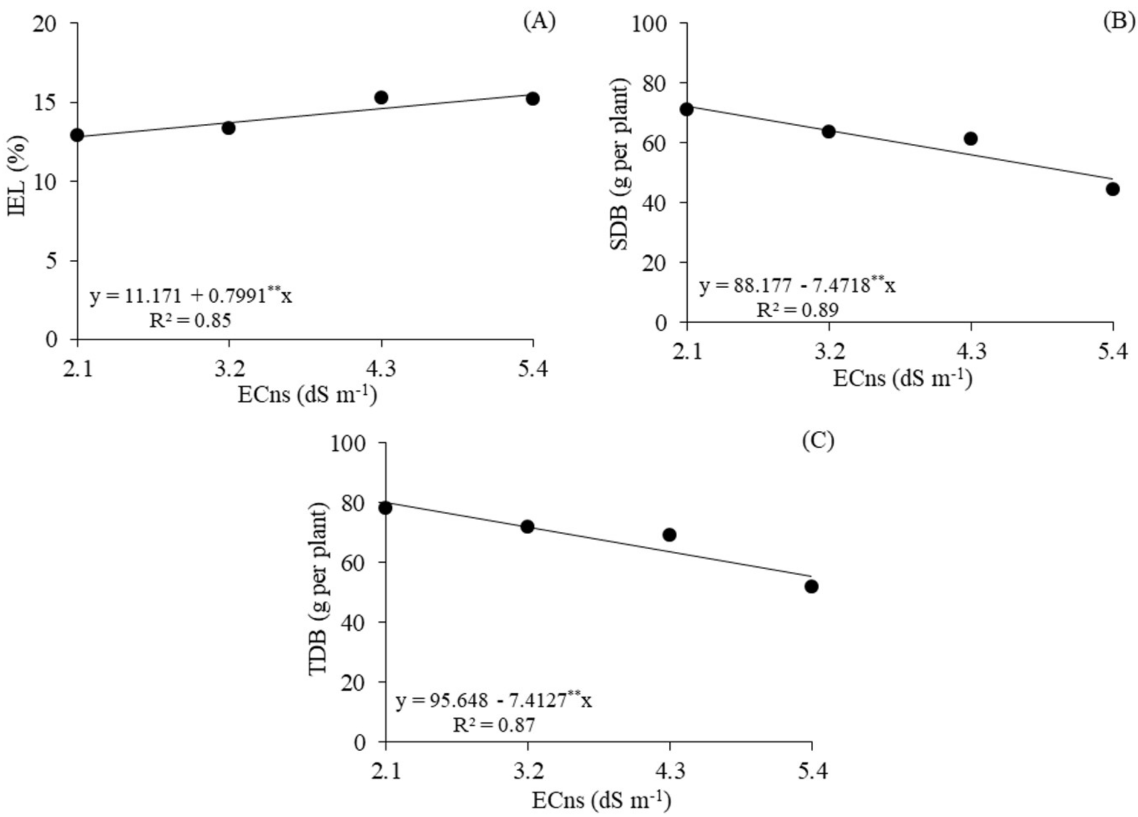

Figure 4. Intercellular electrolyte leakage - IEL (A), shoot dry biomass - SDB (B), and total dry biomass - TDB (C) of ‘Gaúcho’ melon as a function of the levels of electrical conductivity of the nutrient solution - ECns, 74 days after transplanting. X and Y correspond to ECns and salicylic acid concentrations, respectively. ** represent significance at 0.01 probability levels.

Table 4. Summary of the analysis of variance for fresh fruit weight (FFW), equatorial diameter (ED), polar diameter (PD), and soluble solids (SS) in fruits of ‘Gaúcho’ melon cultivated in hydroponic system with different levels of electrical conductivity of nutrient solution (ECns) and foliar application of salicylic acid (SA), 74 days after transplanting.

Source of variation	DF	Mean Squares			
		FFW	ED	PD	SS
ECns	3	520671.87**	202.59**	107.34*	5.49**
Linear Regression	1	1410613.58**	539.75**	279.07**	13.63**
Quadratic Regression	1	113500.75*	19.26*	42.66*	2.70*
Residual 1	15	73,803.43	20.74	5.42	0.83
SA	3	111846.46^{ns}	7.01^{ns}	3.06^{ns}	0.69^{ns}
Linear Regression	1	56649.67^{ns}	6.30^{ns}	2.13^{ns}	0.001^{ns}
Quadratic Regression	1	261008.66*	3.01^{ns}	2.66^{ns}	0.585*
Interaction (ECns × SA)	9	136123.28*	34.22^{ns}	19.22^{ns}	2.27*
Residual 2	65	55,405.50	17.01	4.45	1.05
CV 1 (%)		27.67	12.37	27.40	16.17
CV 2 (%)		23.98	11.20	23.88	18.21

DF: Degrees of freedom; CV: Coefficient of variation; *, ** and ^{ns} significant at 0.05 and 0.01 probability levels and not significant.

(Sousa et al., 2021). Sousa (2015) evaluated the cultivation of mini-watermelon cv. ‘Smile’ under different levels of irrigation water salinity (ECw ranging between 1.0 and 5.0 dS m^{-1}) and verified a reduction of 36.3% in fruit weight at the highest salinity level. Lolaei et al. (2012), when analyzing the effects of the salicylic acid application on strawberries (0, 3, 5, and 7 mM) in different stages of crop development, observed that the concentration of 7 mM caused a reduction in fruit weight.

'Gaúcho' melon plants (Figure 5B) subjected to the electrical conductivity of the nutrient solution of 5.4 dS m^{-1} and foliar application of 2.2 mM of salicylic acid obtained the highest soluble solids content (6.63 ºBrix). On the other hand, plants grown under the lowest level of ECns (2.1 dS m^{-1}) and SA concentration of 0 mM reached the lowest SS value (5.01 ºBrix). The increase in soluble solids in plants subjected to ECns of 5.4 dS m^{-1} and SA concentration of 2.2 mM is related to the functions of SA in reducing the rate of degradation of polysaccharides and consequently to greater availability of simple sugars, besides delaying fruit maturity by inhibiting the production and effects of ethylene (Blankenship and Dole, 2003). Lima et al. (2020b), evaluating the physicochemical composition of fresh fruits of 'BRS 366 Jaburu' West Indian cherry as a function of irrigation water salinity, verified that soluble solids content increased linearly with the increase in salinity levels from 0.6 to 3.8 dS m^{-1}. Barreto et al. (2017), when evaluating the effect of salicylic acid application (0, 1, 2, and 3 mM) in the pre and post-harvest of 'Rubimel' peach, found that the increase in salicylic acid concentrations resulted in an increase in soluble solids content, regardless of storage days.

The equatorial diameter and polar diameter of 'Gaúcho' melon fruits (Figures 6A and 6B) decreased with increasing salinity of the nutrient solution, with reductions of 4.37 and 2.57% per unit increment in ECns, respectively. When comparing melon plants grown under ECns of 5.4 dS m^{-1} to those that received the lowest salinity level of nutrient solution (2.1 dS m^{-1}), reductions of 15.90 and 8.98% (6.36 and 4.56 cm) were found in ED and PD, respectively. Reduction in fruit size results from the effects of high salt concentrations in the soil solution, which inhibits the absorption of water and nutrients by plants. In addition, it interferes with photosynthetic efficiency due to several factors, such as cell membrane dehydration, ionic toxicity, reduction in intercellular CO_2 concentration

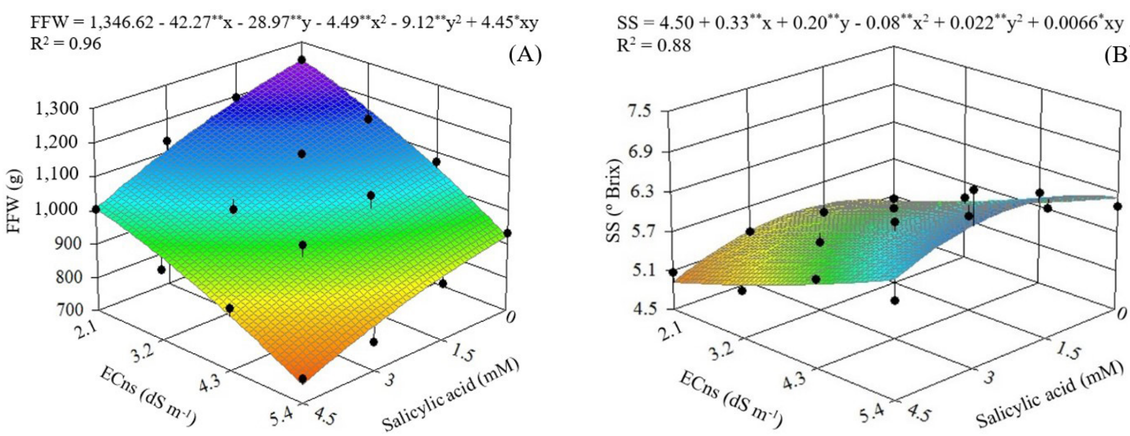

Figure 5. Fresh fruit weight - FFW (A) and soluble solids content - SS (B) of 'Gaúcho' melon fruits, as a function of the interaction between the levels of electrical conductivity of the nutrient solution - ECns and foliar application of salicylic acid. X and Y correspond to ECns and salicylic acid concentrations, respectively. * and ** represent significance at 0.05 and 0.01 probability levels, respectively.

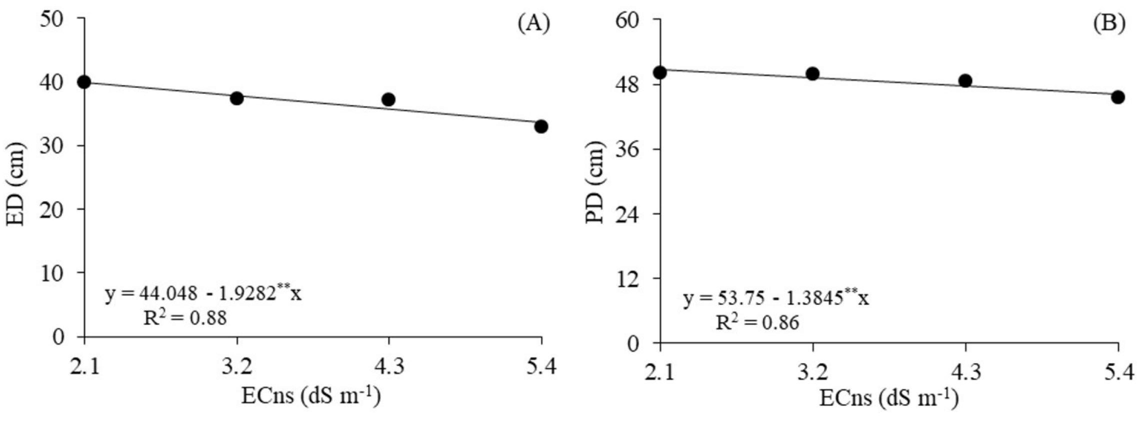

Figure 6. Equatorial diameter - ED (A) and polar diameter - PD (B) of fruits of 'Gaúcho' melon cultivated in a hydroponic system with different levels of electrical conductivity of the nutrient solution - ECns and exogenous application of salicylic acid. ** represents significance at 0.01 probability level.

by stomatal closure, and changes in enzymatic activity (Silva et al., 2020a).

Lima et al. (2020c), when evaluating the production of mini-watermelon cv. 'Sugar Baby' irrigated with saline waters (ECw: 0.3 to 4.3 dS m^{-1}), also observed that the increase in ECw levels led to a reduction in the equatorial and polar diameters of the fruits, equal to 6.77 and 6.50% per unit increment in ECw. The authors attributed the decrease in fruit size to the diversion of energy to the maintenance of metabolic activities, which consequently led to changes in the distribution of photoassimilates among the different organs of the plant.

4. Conclusions

The foliar application of salicylic acid concentrations does not mitigate the deleterious effects of salt stress on the morphophysiology and yield of melon grown in the hydroponic system. The concentration of 4.5 mM of salicylic acid intensified the harmful effects of the salinity of the nutrient solution on gas exchange and the fresh weight of hydroponic melon fruit.

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