DOI: 10.5433/1679-0359.2022v43n3p1145

Induction of salt stress tolerance in cherry tomatoes under different salicylic acid application methods

Indução a tolerância ao estresse salino em tomate cereja sob diferentes métodos de aplicação de ácido salicílico

André Alisson Rodrigues da Silva[1]*; Luana Lucas de Sá Almeida Veloso[2]; Geovani Soares de Lima[3]; Lauriane Almeida dos Anjos Soares[4]; Lucia Helena Garófalo Chaves[3]; Francisco de Assis da Silva[1]; Mirandy dos Santos Dias[1]; Pedro Dantas Fernandes[3]

Highlights

Salt stress reduces plant photosynthetic pigment levels and photochemical efficiency.
Water salinity drastically affects gas exchange.
Foliar spray with salicylic acid minimizes the deleterious effects of salinity.

Abstract

Salinity is among the biggest challenges of irrigated agriculture, as it induces several limitations to the growth and physiology of plants; therefore, strategies should be sought that minimize its impacts on plants. In this scenario, the present study was developed to examine the effects of different salicylic acid (SA) application methods on photosynthetic pigments, chlorophyll *a* fluorescence, gas exchange, and biomass accumulation of cherry tomato under salt stress. The study was carried out in a greenhouse, using a Regosol soil (Psamments) with a sandy-loam texture. The treatments were distributed in a completely randomized design, in a 2 × 4 factorial arrangement consisting of two levels of electrical conductivity in the irrigation water (0.6 or 2.6 dS m^{-1}) and four salicylic acid application methods (M1 = without SA [control] application; M2 = foliar spray; M3 = irrigation; or M4 = spray and irrigation), with five replicates. Irrigation with 2.6 dS m^{-1} salinity water negatively affected chlorophyll *a* fluorescence and the total chlorophyll, chlorophyll *a*, and

---

[1] Doctoral Scholar of Agricultural Engineering Course, Center of Technology and Natural Resources, Universidade Federal de Campina Grande, UFCG, Campina Grande, PB, Brazil. E-mail: andrealisson_cgpb@hotmail.com; agrofdsilva@gmail.com; mirandydias@gmail.com

[2] Post Doctoral Fellow, Post Graduate Program in Agricultural Engineering, Center of Technology and Natural Resources, UFCG, Campina Grande, PB, Brazil. E-mail: luana_lucas_15@hotmail.com

[3] Profs., Post Graduate Program in Agricultural Engineering, Center of Technology and Natural Resources, UFCG, Campina Grande, PB, Brazil. E-mail: geovani.soares@pq.cnpq.br; lhgarofalo@hotmail.com; pedrodantasfernandes@gmail.com

[4] Profa, Academic Unit of Agricultural Sciences, Center of Agrifood Science and Technology, UFCG, Pombal, PB, Brazil. E-mail: laurispo.agronomia@gmail.com

* Author for correspondence

Received: Apr. 09, 2021 - Approved: Mar. 09, 2022

carotenoid contents, in addition to inhibiting stem dry biomass production and root/shoot ratio. Foliar spray with salicylic acid minimized the deleterious effects of salt stress on gas exchange and chlorophyll content and increased leaf and root dry biomass accumulation and the root/shoot ratio of cherry tomatoes at 120 days after sowing.

Key words: Acclimatization. Irrigation. Mitigation. *Solanum lycopersicum* L.. Salinity.

Resumo

A salinidade está entre os maiores desafios da agricultura irrigada, induzindo várias limitações no crescimento e na fisiologia das plantas, fazendo necessária a busca por estratégias que visem minimizar seus impactos sobre as plantas. Neste contexto, objetivou-se avaliar os efeitos de diferentes métodos de aplicação de ácido salicílico sobre os pigmentos fotossintéticos, a fluorescência da clorofila *a*, as trocas gasosas e o acúmulo de fitomassa de tomate cereja sob estresse salino. O estudo foi conduzido em casa de vegetação, utilizando-se um Neossolo Regolítico Psamitico de textura franco-arenosa. Os tratamentos foram distribuídos em delineamento inteiramente casualizados, em arranjo fatorial 2 × 4, sendo dois níveis de condutividade elétrica da água de irrigação (0,6 e 2,6 dS m^{-1}) e quatro métodos de aplicação de ácido salicílico (M1= Testemunha - sem aplicação de AS, M2= via pulverização, M3= via irrigação e M4= pulverização e irrigação), com cinco repetições. A irrigação com água de 2,6 dS m^{-1} afetou de forma negativa a fluorescência da clorofila *a*, os teores de clorofila a, total e carotenóides, além de inibir a produção de fitomassa seca de caule e a relação raiz/parte aérea. O método de aplicação de ácido salicílico via pulverização foliar minimizou os efeitos deletérios do estresse salino sobre as trocas gasosas e teores de clorofila *b* e proporcionou maior acúmulo de fitomassa seca de folha e raiz, aumentando também a relação raiz/parte aérea de tomate cereja, aos 120 dias após a semeadura.

Palavras-chave: *Solanum lycopersicum* L. Salinidade. Irrigação. Mitigação. Aclimatação.

Introduction

Tomato (*Solanum lycopersicum* L.) is a vegetable widely consumed and produced worldwide. In 2020, Brazil produced about 3,956,559 t of the fruit, ranking among the ten largest tomato producers (Instituto Brasileiro de Geografia e Estatística [IBGE], 2020). In northeastern Brazil, tomato production was 496,721 t, of which 241,200 t came from the main producing state, Bahia, from an area of 5,340 ha (IBGE, 2020).

As one of the major tomato groups sold in Brazil (Santa Cruz, Carmen, Italian, cherry, and industrial), cherry tomatoes are appreciated for their high antioxidant activity, in addition to having high levels of nutrients and soluble solids, rendering them attractive and healthy appetizers in gastronomy (Londoño-Giraldo et al., 2020).

Despite the production potential of the Brazilian northeast, tomato growing is limited due to the use of saline water for irrigation. Its production cycle is drastically affected because the plant is sensitive to the effects of salts in water with electrical conductivity above 2.5 dS m^{-1} (P. R. F. Medeiros, Duarte, Uyeda, Silva, & Medeiros, 2012). Some studies have shown a reduction in the yield of tomato when the crop was subjected to salt stress; e.g., in conventional cultivation, Parvin et al. (2015) reported a 57.2% reduction in yield when the crop was irrigated with water with 8.0 dS m^{-1} salinity. Batista et al. (2021) evaluated the production of tomato cv. Caroline in a hydroponic system under salt stress (2.5 to 8.5 dS m^{-1}) and found a 62% decrease in the yield of plants grown under higher salinity.

The salinity of irrigation water and the soil is one of the main abiotic stresses that lowers the productivity of arable areas to uneconomical levels. This phenomenon is particularly intense in irrigated soils in semi-arid regions, where water with high levels of salts is used to meet the water needs of crops as a way to address the scarcity of quality water (Machado & Serralheiro, 2017; Zörb, Geilfus, & Dietz, 2019).

In recent years, there has been an expansion in vegetable growing in protected environments. However, the accumulation of salts in the soil, resulting from the use of fertilizers and the lack of leaching, has become a limiting factor for production in this cropping system (Azevedo, Oliveira, Martins, Silva, & Ribeiro, 2018). Lima et al. (2016) investigated irrigation with saline water (0.6 and 3.0 dS m-1) in the cultivation of 'All Big' peppers in a protected environment and found that increasing water salinity negatively affected the growth and production of the plants.

Exogenous application of salicylic acid (SA) to plants is an alternative to induce tolerance to salt stress in an attempt to ensure agricultural activities in regions with quantitative and qualitative shortages of water resources. This organic acid is a secondary metabolite produced by the plant organism that is responsible for numerous regulatory functions such as floral induction, growth, enzyme biosynthesis, stomatal movements, membrane protection, and cellular respiration. Additionally, SA acts as a signaling molecule that induces tolerance to biotic and abiotic stresses (Souri & Tohidloo, 2019; Horváth et al., 2015).

Salicylic acid can be applied through different methods (soaking, spraying, via the root, or associations between these), yet the approach that most reduces salt stress in plants is still not known. There are reports that foliar application of SA in Mulungu attenuated the initial fluorescence of the plants (Figueiredo et al., 2019). Soaking pumpkin seeds in SA improved germination kinetics and mitigated the effects of water salinity during the initial growth of pumpkin seedlings (Guirra et al., 2020). In tomato, foliar application of SA has been shown to generally induce tolerance to salt stress (Gharbi, Lutts, Dailly, & Quinet, 2018).

Given the above-described context, the present study was developed to evaluate the effects of different methods of application of SA on photosynthetic pigments, chlorophyll a fluorescence, gas exchange, and biomass accumulation of cherry tomato under salt stress.

Material and Methods

The experiment was carried out from October 2020 to February 2021 in a protected environment (greenhouse) belonging to the Academic Unit of Agricultural Engineering (UAEA) at the Federal University of Campina Grande (UFCG), in Campina Grande - PB, Brazil (7°15'18" S, 35°52'28" W, 550 m asl). Figure 1 shows temperature (maximum and minimum) and average relative humidity data of the experimental site.

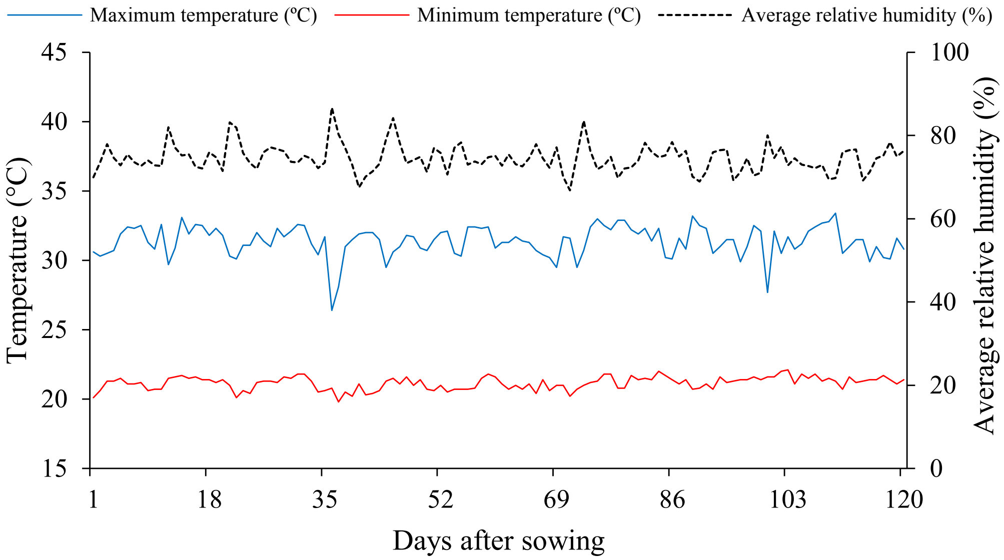

Figure 1. Air temperature (maximum and minimum) and mean relative humidity recorded inside the greenhouse during the experimental period.

Treatments resulted from the combination of two levels of electrical conductivity in the irrigation water (ECw: 0.6 or 2.6 dS m^{-1}) and four SA application methods (M1 = no application of SA [control]; M2 = foliar spray; M3 = irrigation; or M4 = spray and irrigation), in a 2 × 4 factorial arrangement distributed in a completely randomized design with five replicates. In both SA application methods, the concentration of 1 mM was used.

The SA concentrations adopted in both application methods were based on studies developed by Poursakhi, Razmjoo and Karimmojeni (2019) with the tomato crop. The water salinity levels, in turn, were defined according to Vieira, Nobre, Dias and Pinheiro (2016).

Cherry tomato cultivar Carolina was used. This material has indeterminate growth, bears small, red fruits weighing between 10 and 12 g, and has a cycle of 110 to 120 days. The cultivar is resistant to verticillium wilt (*Verticillium alboatrum* and *Verticillium dahliae*) and Fusarium (*Fusarium oxysporum*). In addition, the fruit has a longer shelf life, of around 18 days after harvest, and can be grown in small areas, reaching high yields with excellent financial returns (Matos et al., 2021).

For the experiment, polyethylene pots (Citropote®; 8 dm^3) were covered with a geotextile layer (Bidim OP 30) and filled with a layer of 0.3 kg of gravel (no. 0) followed by 8 kg of soil classified as Regosol (Psamments - United States, 2014). The soil was collected at a depth of 0-30 cm in the municipality of Riachão do Bacamarte - PB, Brazil. Physicochemical attributes of the soil (Table 1) were determined according to Teixeira, Donagemma, Fontana and Teixeira (2017).

Table 1
Chemical and physical attributes of the soil used in the experiment, before the application of treatments

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

OM - organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1M KCl pH 7.0; Na^+ and K^+ extracted using 1M NH4OAc pH 7.0; Al^{3+} and H^+ extracted with 0.5M CaOAc pH 7.0; ESP - exchangeable sodium percentage; ECse - electrical conductivity of the saturation extract; SL - sandy loam; AW - available water; AD - apparent density; PD - particle density; * - field capacity; ** - wilting point.

Irrigation waters with different levels of electrical conductivity were prepared by dissolving the NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts at the equivalent proportion of 7:2:1, respectively, in water from local supply (ECw = 0.32 dS m^{-1}). This proportion is commonly found in water sources used for irrigation on small farms in northeastern Brazil (J. F. D. Medeiros, Lisboa, Oliveira, Silva, & Alves, 2003). In the preparation of irrigation water, we considered the ratio between ECw and the salt concentration (Richards, 1954), according to Eq. 1:

$$\mathrm{C}\ (\mathrm{mmol_c L^{-1}}) = 10 \times\ \mathrm{ECw}\ (\mathrm{dS\ m^{-1}}) \ldots\ldots (1),$$

where C - concentration of salts to be added (mmol$_c$ L^{-1}); and ECw - electrical conductivity of water (dS m^{-1}).

Thirty days after sowing (DAS), irrigation with saline water was started in a two-day irrigation shift, applying water so as to maintain soil moisture close to field capacity. The volume to be applied was determined according to the water requirement of the plants, which was estimated by the water balance, according to Eq. 2:

$$\mathrm{Vi} = \frac{(\mathrm{Vp-Vd})}{(1-\mathrm{LF})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2),$$

where Vi - volume of water to be applied in irrigation (mL); Vp - volume applied in the previous irrigation event (mL); Vd - volume drained after previous irrigation event (mL); and LF - leaching fraction of 0.10, applied every 30 days.

The SA concentration was obtained from a dilution in 30% of ethyl alcohol (95.5%), as it is a substance with low solubility in water at room temperature. To reduce the surface tension of the droplets on the leaf surface, the adjuvant Wil fix was used in the preparation of the solution at a concentration of 0.5 mL L^{-1} of solution.

Applications were started five days before the application of saline water; i.e., at 25 DAS, sprays were performed on the abaxial and adaxial surfaces. Subsequent applications were carried out at 15-day intervals, until 85 DAS (Table 2), using a sprayer, between 17h00 and 17h30. The average volume applied per plant in each spray was 70 mL. The plants subjected to application via irrigation were irrigated with a SA volume of 50 mL on the same days of spraying.

Table 2
Dates of application of salicylic acid by different delivery methods during the experiment

APPLICATION	Method 1 (Control)	Method 2 (Spray)	Method 3 (Irrigation)	Method 4 (Spray+Irrigation)
1st	-	25 DAS (10/25/2020)	25 DAS (10/25/2020)	25 DAS (10/25/2020)
2nd	-	40 DAS (11/09/2020)	40 DAS (11/09/2020)	40 DAS (11/09/2020)
3rd	-	55 DAS (11/24/2020)	55 DAS (11/24/2020)	55 DAS (11/24/2020)
4th	-	70 DAS (12/09/2020)	70 DAS (12/09/2020)	70 DAS (12/09/2020)
5th	-	85 DAS (12/24/2020)	85 DAS (12/24/2020)	85 DAS (12/24/2020)

The area was topdressed with nitrogen, potassium, and phosphorus, as recommended by Novais, Neves and Barros (1991). For this step, 0.76 g urea, 2.0 g potassium chloride, and 3.87 g monoammonium phosphate were applied, corresponding to 100, 150, and 300 mg kg^{-1} of N, K_2O, and P_2O_5, respectively. These rates were split into four application events via fertigation, at 15-day intervals, the first taking place at 40 DAS.

A micronutrient solution of the commercial product Dripsol® micro (concentration: 1.0 g L^{-1}) was applied fortnightly. The product contained 1.1% Mg, 4.2% Zn, 0.85% B, 3.4% Fe, 3.2% Mn, 0.5% Cu, and 0.05% Mo and was applied foliarly, on the adaxial and abaxial surfaces, using a backpack sprayer.

During the experiment, all the cultivation and phytosanitary treatments recommended for the crop were adopted; the emergence of pests and diseases was monitored; and control measures were taken when necessary.

At 100 DAS, the levels of photosynthetic pigments (chlorophylls a and b, total chlorophyll, and carotenoids) were quantified by the method proposed by Arnon (1949), whereby plant extracts are made from samples of discs of the blade of the third mature leaf from the apex. With these extracts, the concentrations of chlorophyll and carotenoids in the solutions were determined using the spectrophotometer at the absorbance wavelengths (ABS) of 470, 647, and 663 nm, using the following equations:

$$\text{Chlorophyll } a \text{ (Cl } a) = (12.25 \times \text{ABS}_{663}) - (2.79 \times \text{ABS}_{647}) \text{ ....(3)}$$

$$\text{Chlorophyll } b \text{ (Cl } b) = (21.5 \times \text{ABS}_{647}) - (5.10 \times \text{ABS}_{663}) \text{ ....(4)}$$

$$\text{Total chlorophyll (Cl } T) = (7.15 \times \text{ABS}_{663}) + (18.71 \times \text{ABS}_{647}) \text{ .... (5)}$$

$$\text{Carotenoids (Car)} = ((1000 \times \text{ABS}_{470}) - (1.82 \times \text{Cl } a) - (85.02 \times \text{Cl } b)) /198 \text{...(6)}$$

The Cl*a*, Cl *b*, Cl *T*, and carotenoid values found in the leaves will be expressed in mg g^{-1} of fresh matter.

Gas exchange was evaluated at 100 DAS, by determining stomatal conductance (gs), transpiration (E), CO_2 assimilation rate (A), and intercellular CO_2 concentration (Ci). From these data, instantaneous water use efficiency (*iWUE*) (*A/E*) and instantaneous carboxylation efficiency (*iCE*) (*A/Ci*) were quantified.

Gas exchange measurements were performed on the third leaf, counted from the apex of the main branch of the plant. The irradiation of 1200 μmol photons m-2 s-1 and the air flow rate of 200 mL min-1 were adopted, using the LCPro+ portable photosynthesis system (ADC BioScientific Ltd.).

Chlorophyll *a* fluorescence was also determined at 100 DAS on the same leaf used for gas exchange, using a OS5p pulse modulated fluorimeter (Opti Science) and applying the Fv/Fm protocol, to determine the following fluorescence induction variables: initial (Fo), maximum (Fm), and variable (Fv = Fm – Fo) fluorescence and quantum efficiency of photosystem II (Fv/Fm). This protocol was performed after adapting the leaves to the dark for a period of 30 min, using a clip of the equipment and ensuring that all acceptors were oxidized; i.e., with the reaction centers open.

At 120 DAS, the dry biomass of leaves (LDB), stems (SDB), and root (RDB) and the root/shoot ratio (R/S) were measured. To obtain the dry biomass, the stem of each plant was cut close to the ground and then the different parts (stem, leaf, and root) were separated and packed in a paper bag, which was then set to dry in a forced-air oven at a temperature of 65 °C until constant weight. Afterwards, the material was weighed, and the results represented LDB, SDB, and RDB.

Data were subjected to the distribution normality test (Shapiro-Wilk test) at a probability level of 0.05. Means referring to the levels of electrical conductivity in the water and SA application methods were compared by Tukey's test ($p \leq 0.05$), using SISVAR-ESAL statistical software (Ferreira, 2019).

Results and Discussion

The interaction between salt levels (SL) and salicylic acid (SA) concentrations only significantly influenced chlorophyll b (Table 3). In contrast, the salt levels significantly affected all analyzed variables. Salicylic acid concentrations provided a significant effect on Cl b, Cl T, and Car.

Table 3

Summary of analysis of variance for chlorophylls *a* (Cl *a*) and *b* (Cl *b*), total chlorophyll (Cl *T*), and carotenoids (Car) of cherry tomatoes irrigated with saline water and subjected to different methods of application of salicylic acid, at 100 days after sowing

Source of variation	DF	Mean square			
		Cl a	Cl b	Cl T	Car
Salt level (SL)	1	37507.05**	10495.33**	66145.69**	3907.74*
Application method (AM)	3	10112.38^{ns}	3236.74**	17843.79*	2462.64*
Interaction (SL × AM)	3	6094.31^{ns}	7452.21**	1828.65^{ns}	1915.82^{ns}
Residual	32	3874.39	675.82	4333.53	651.41
CV (%)		18.59	19.51	14.39	24.78

ns, **, * not significant and significant at $p \leq 0.01$ and at $p \leq 0.05$, respectively.

For Cl *a* (Figure 2A), Cl *T* (Figure 2C), and Car (Figure 2E), the cherry tomato plants irrigated with water with 2.6 dS m^{-1} salinity showed reductions of 16.8% (61 .3 mg g^{-1} FW), 16.3% (81.4 mg g^{-1} FW), and 28.8% (37 mg g^{-1} FW), respectively, relative to the plants under irrigation with water with 0.6 dS m^{-1} salinity. By analyzing chlorophyll *b* (Figure 2B), we observe that the plants of control treatment stood out in comparison with those that received the other SA application methods when cultivated with low-salinity water (0.6 dS m^{-1}). On the other hand, when exposed to salt stress, the plants of control treatment exhibited a 10.6% reduction (16.7 mg g^{-1} FW) relative to those irrigated with water with 0.6 dS m^{-1} salinity. However, SA application via foliar spray stood out when the cherry tomato plants were irrigated with higher-salinity water (2.6 dS m^{-1}), significantly increasing Cl *b* by 36.8% (51.9 mg g^{-1} FW) relative to the control plants irrigated with the same salt level.

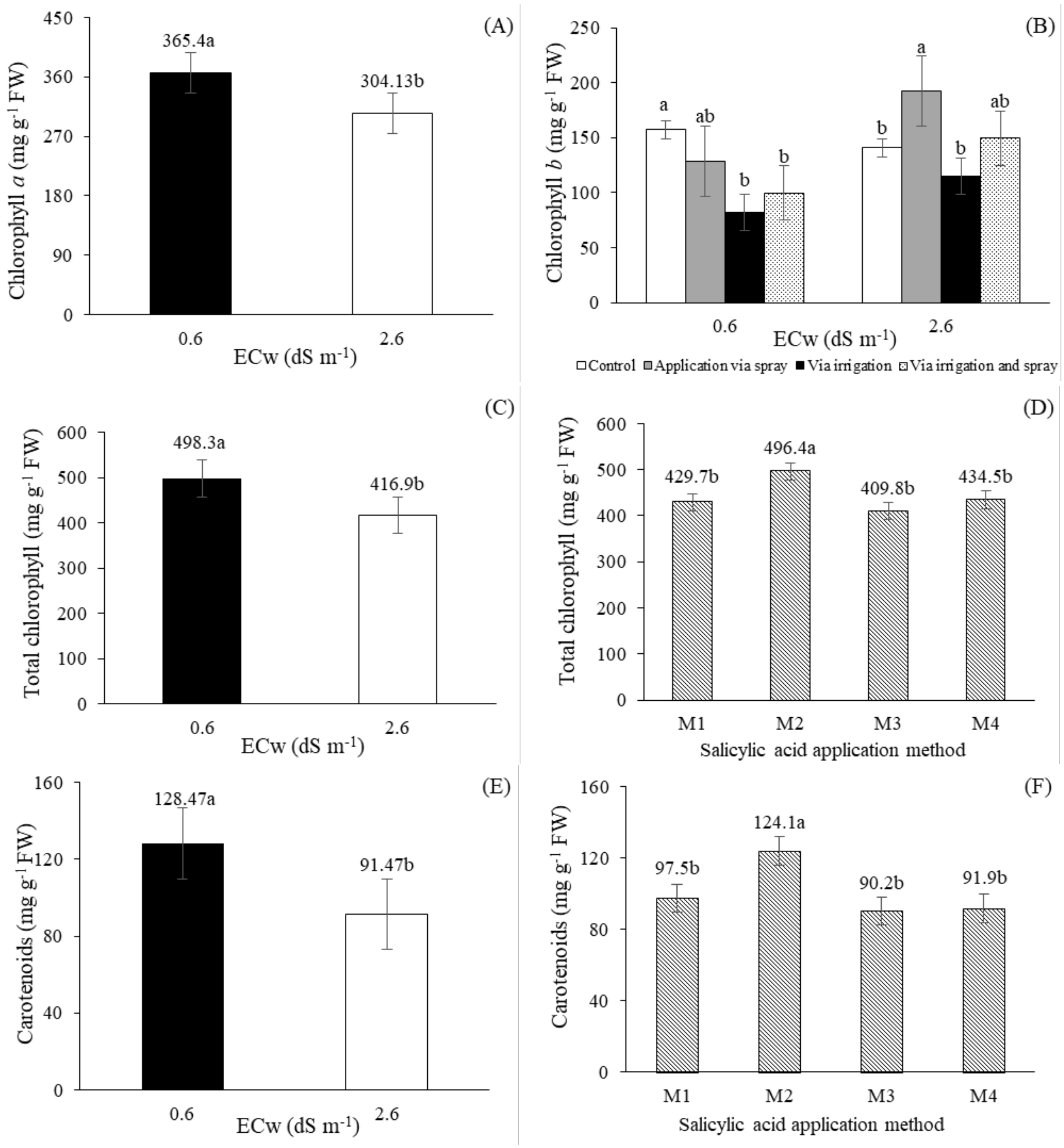

Figure 2. Chlorophyll *a* (Cl *a*; A), total chlorophyll (Cl *T*; C), and carotenoids (Car; E) as a function of electrical conductivity in the irrigation water (ECw); chlorophyll *b* (Cl *b*; B) as a function of the interaction between salt levels and salicylic acid application methods; and total chlorophyll (Cl *T*; D) and carotenoids (Car; F) as a function of salicylic acid application methods, at 100 days after sowing.

Means followed by different letters differ significantly between treatments by Tukey's test ($p \leq 5\%$). Vertical bars represent the standard error (n=5). M1 - control (no application); M2 - application via spray; M3 - via irrigation; M4 - via irrigation and spray.

The reduction in chlorophyll levels in plants exposed to water salinity is probably due to the increase in the activity of the chlorophyllase enzyme, which degrades the molecules of this photosynthetic pigment, as observed by Dias, Lima, Pinheiro, Gheyi and Soares (2019) in the acerola tree. Salt stress reduces the production of photosynthetic pigments and induces the degradation of β-carotene, causing a decrease in the content of carotenoids, which are integrated components of thylakoids that act on the absorption and transfer of light to chlorophyll (A. A. R. Silva, Bezerra, Lacerda, Sousa, & Chagas, 2016).

The total chlorophyll (Figure 2D) and carotenoid (Figure 2F) levels of cherry tomatoes cultivated with foliar spray of SA (M2) were statistically superior to those that were subjected to the other SA application methods. Plants in the control treatment and those which received the application via spraying and irrigation simultaneously did not differ statistically from each other.

There was a significant SL × SA interaction effect ($p \leq 0.01$) on all gas exchange variables, except for the intercellular CO_2 concentration (Table 4). Salt levels also significantly influenced gas exchange. The SA application methods significantly affected *E, A, iCE,* and *iWUE*.

Table 4
Summary of analysis of variance for intercellular CO2 concentration (Ci), stomatal conductance (gs), transpiration (E), CO2 assimilation rate (A), instantaneous carboxylation efficiency (iCE), and instantaneous water use efficiency (iWUE) of cherry tomato plants irrigated with saline water and subjected to different salicylic acid application methods, at 100 days after sowing

Source of variation	DF	Mean square					
		Ci	*gs*	*E*	*A*	*iCE*	*iWUE*
Salt level (SL)	1	14630.63**	0.014*	2.32**	9.02*	$9.1\text{x}10^{-4}$**	2.58**
Application method (AM)	3	439.43^{ns}	0.007^{ns}	1.02**	11.29**	$2.4\text{x}10^{-4}$**	4.03**
Interaction (NS × AM)	3	77.16^{ns}	0.014**	0.41**	20.63**	$3.5\text{x}10^{-4}$**	7.16**
Residual	32	288.38	0.004	0.04	1.99	$3.4\text{x}10^{-5}$	0.24
CV (%)		6.93	27.77	7.83	16.17	16.04	13.55

ns, **, * not significant and significant at $p \leq 0.01$ and at $p \leq 0.05$, respectively.

The intercellular CO_2 concentration (Figure 3A) of tomatoes grown under water with 2.6 dS m^{-1} salinity was statistically higher than those subjected to irrigation with 0.6 dS m^{-1}. When we compare the *Ci* of plants irrigated with water with higher salinity (2.6 dS m^{-1}) and those cultivated with the lowest salinity level (0.6 dS m^{-1}) in relative terms, an increase of 17.3% (39 μmol CO_2 m^{-2} s^{-1}) is observed.

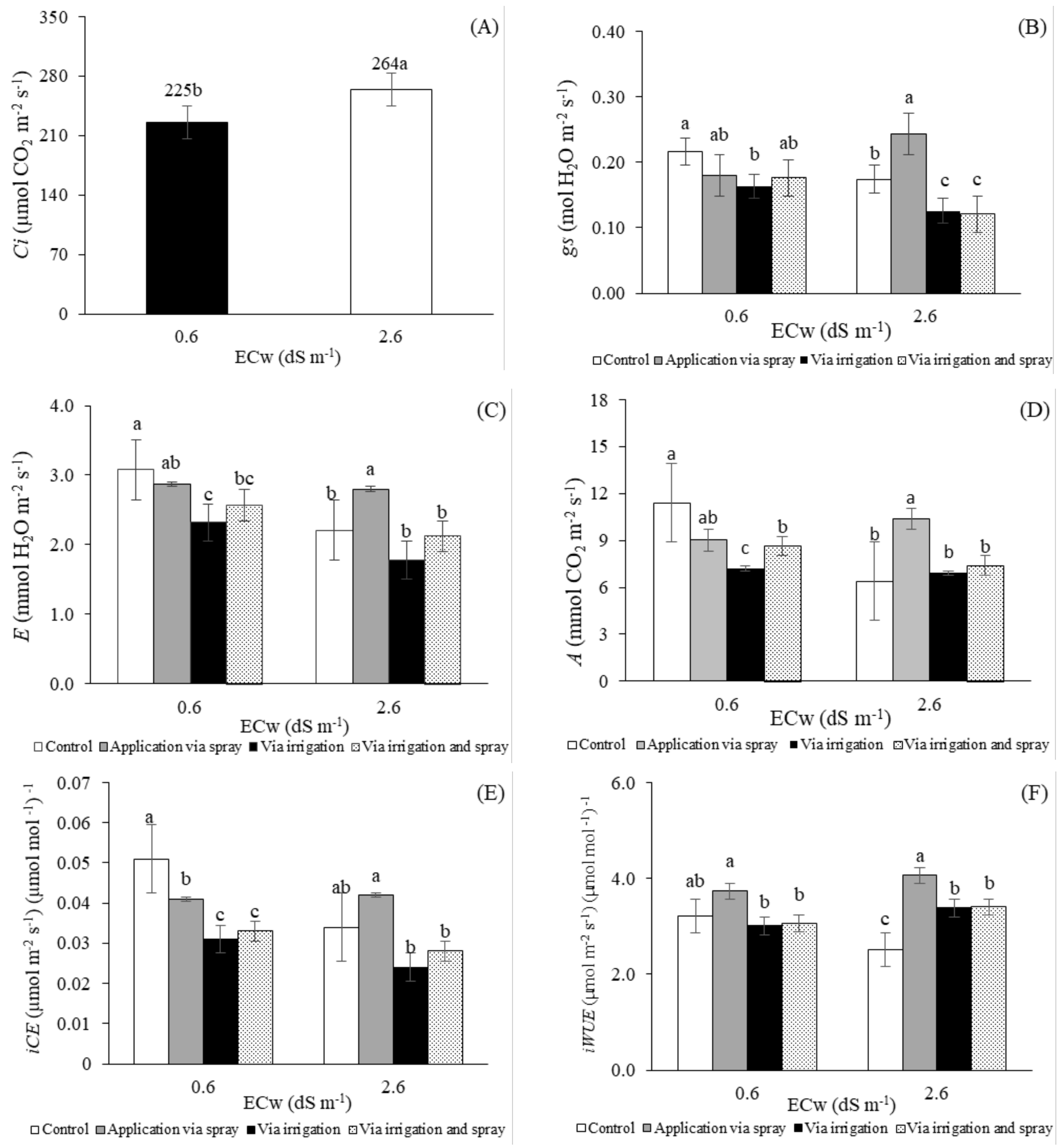

Figure 3. Intercellular CO_2 concentration (*Ci*; A) as a function of the electrical conductivity of irrigation water (ECw); stomatal conductance (*gs*; B), transpiration (*E*; C), CO_2 assimilation rate (A; D), instantaneous carboxylation efficiency (*iCE*; E), and instantaneous water use efficiency (*iWUE*; F) of tomato as a function of the interaction between salt levels and salicylic acid application methods, at 100 days after sowing.

Means followed by different letters differ significantly between treatments by Tukey's test ($p \leq 5\%$). Vertical bars represent the standard error (n=5).

Overall, by examining the variables of *gs*, *E*, *A*, *iCE*, and *iWUE* (Figure 3B to 2F), we note that the plants of control treatment stood out over those under the other SA application methods when grown under low-salinity water (0.6 dS m^{-1}). When irrigated with water with electrical conductivity of 2.6 dS m^{-1}, the plants of control treatment exhibited reductions of 19.4, 28.2, 43.9, 33.3, and 21.8% in gs, E, A, iCE, and iWUE, respectively.

Nonetheless, the foliar spray application method was highlighted when the tomato plants were irrigated with higher-salinity water (2.6 dS m^{-1}), having their *gs*, *E*, *A*, *iCE*, and *iWUE* increased by 39, 6, 26.7, 62.0, 23.5, and 61.8%, respectively, in relation to the control plants irrigated with the same saline level. These results show that foliar application of SA can improve gas exchange in tomato plants under salt stress.

Stomatal closure is an early response of plants to salt stress, in an attempt to reduce water loss and, consequently, the absorption of salts from the soil solution without compromising photosynthetic activity (Dias et al., 2018; Bezerra et al., 2018a). The results of this study are in agreement with the reports by Martínez-Cuenca et al. (2020), who evaluated the effects of salt stress on cherry tomato plants and found reductions in gas exchange under salt stress conditions.

The reductions in gas exchange under salt stress conditions can be attributed to the degradation of photosynthetic pigments (Figure 2), as they are an integral part of the light capture complex for the photosynthesis process, reductions in chlorophyll fluorescence (Figure 4), PSII photoinhibition, changes in the membrane-bound ATPase enzyme complex, and a decrease in Rubisco activity (Lawlor & Cornic, 2002).

However, the application of SA via foliar spray was able to attenuate the deleterious effects of salinity on chlorophyll *b* (Figure 2B) and on the gas exchange variables (Figure 3) of the cherry tomatoes. Khan, Asgher and Khan (2014) and Ahmad et al. (2018) described that SA increases pigment content, improves transpiration rates and photosynthetic electron transport, maintains antioxidant enzyme activities, and improves photosynthetic activity under salt stress.

The application of SA via foliar spray increased the *iWUE* of the cherry tomato plants regardless of the irrigation water salinity level, although the effect of SA on the increase in *iWUE* under higher salinity (2.6 dS m^{-1}) was greater than under low salinity (0.6 dS m^{-1}). Salicylic acid is an endogenous phenolic-type regulator that regulates the physiological and biochemical processes of plants to alleviate the deleterious effects of various stresses, such as salinity (Ghassemi-Golezani, Farhangi-Abriz, & Bandehagh, 2018).

There was a significant difference in the irrigation water salinity levels for the chlorophyll *a* fluorescence variables (Table 5). On the other hand, SA application methods and the interaction between application methods and SL did not significantly influence the studied variables, at 100 days after sowing.

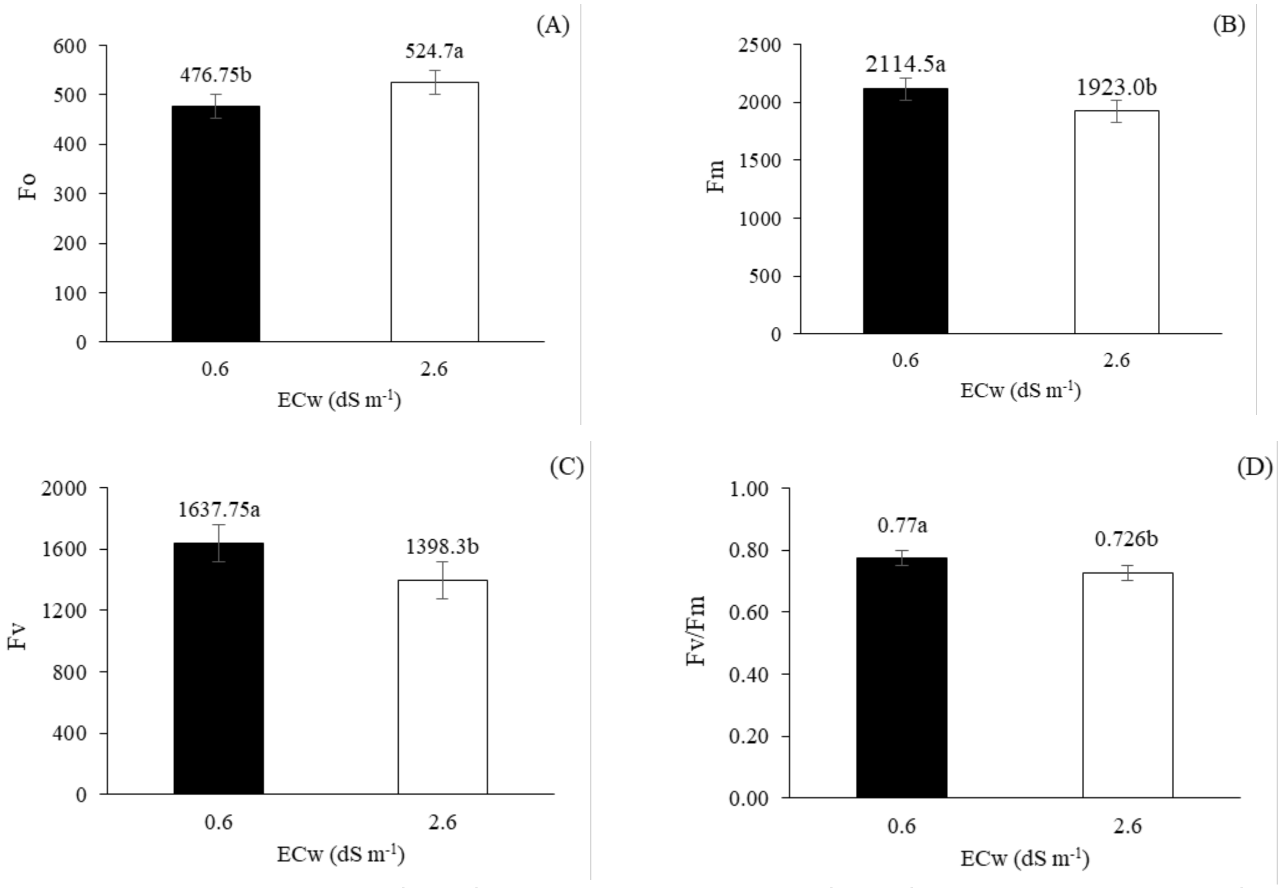

Figure 4. Initial fluorescence (Fo; A), maximum fluorescence (Fm; B), variable fluorescence (Fv; C), and quantum efficiency of photosystem II (Fv/Fm; D) of tomato as a function of the electrical conductivity in the irrigation water (ECw), at 100 days after sowing.

Means followed by different letters differ significantly between treatments by Tukey's test ($p \leq 5\%$). Vertical bars represent the standard error (n=5).

Table 5

Summary of analysis of variance for initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), and quantum efficiency of photosystem II (Fv/Fm) in cherry tomato plants irrigated with saline water and subjected to different salicylic acid application methods, at 100 days after sowing

Source of variation	DF	Mean square			
		Fo	Fm	Fv	Fv/Fm
Salt level (SL)	1	22992.03**	366722.50**	573363.02**	2.29x10^{-2}**
Application method (AM)	3	3720.89^{ns}	14685.9^{ns}	10182.29^{ns}	6.9x10^{-4ns}
Interaction (NS × AM)	3	365.09^{ns}	19389.37^{ns}	17032.63^{ns}	2.6x10^{-4ns}
Residual	32	838.81	6449.85	7909.72	3.5x10^{-4}
CV (%)		5.78	3.98	5.86	2.48

ns, **, * not significant and significant at $p \leq 0.01$ and at $p \leq 0.05$, respectively.

The initial fluorescence of cherry tomatoes increased as a function of irrigation, with a 10% increase (48) achieved at 2.6 dS m^{-1} relative to the plants cultivated with ECw of 0.6 dS m^{-1} (Figure 4A). In contrast to Fo, the maximum fluorescence of cherry tomatoes decreased significantly with increasing salinity of irrigation water (Figure 4B). Plants irrigated with water with 2.6 dS m^{-1} salinity showed a reduction of 9.06% compared with those irrigated with low-salinity water (0.6 dS m^{-1}); i.e., a decrease of 191.5. Fluorescence (Figure 4C) and the quantum efficiency of photosystem II (Figure 4d) followed the same trend observed for maximum fluorescence. Plants irrigated with water with 0.6 dS m^{-1} salinity were superior by 17.12% (239.5) in Fv and by 6.61% (0.048) in Fv/Fm (Figure 4C and 4D) compared with those irrigated with high-salinity water (2.6 dS m^{-1}).

Initial fluorescence is associated with the oxidation capacity of quinone; therefore, the greater the increase in Fo, the lower the ability of quinone to receive electrons and consequently transfer energy to photosystem II (PSII) (Sá et al., 2018). Thus, the increase in Fo values under salt stress conditions may be a consequence of damage to the PSII reaction center or a reduction in the excitation capacity to transfer energy to the reaction center (Baker, 2008).

The decrease in maximum fluorescence with increasing water salinity may be an indication of little efficiency in quinone photoreduction and in the flow of electrons between the photosystems. This results in low activity of PSII in the thylakoid membrane, which directly influences the electron flow between photosystems (M. M. P. Silva et al., 2006; Tatagiba, Moraes, Nascimento, & Peloso, 2014). According to Zanandrea et al. (2006), the fluorescence variable represents the flow of electrons from the reaction center of photosystem II to plastoquinone. Any change in Fo or Fm causes a decrease in the primary electron acceptor quinone of photosystem II.

Irrigation water salinity also negatively affected the quantum efficiency of photosystem II of the cherry tomato plants, as measured by the Fv/Fm ratio. As stated by Melo et al. (2010), Fv/Fm refers to the excitation energy transfer capacity and expresses the efficiency of capturing this energy by the open reaction centers of PSII. It is thus clear that there was damage to PSII, since the Fv/Fm ratio found in plants irrigated with 2.6 dS m^{-1} salinity was below the index (0.75 electrons $quantum^{-1}$) considered as the threshold to damage the photosynthetic apparatus of plants (Santos et al., 2010). When the photosynthetic apparatus is intact, Fv/Fm values vary between 0.75 and 0.85 electrons $quantum^{-1}$ (Reis & Campostrini, 2011).

There was a significant effect of the interaction between salt levels and SA application methods only on the dry biomass of leaves and roots (Table 6). Salinity levels significantly affected all analyzed variables. On the other hand, the SA application methods significantly affected all variables, except stem dry biomass.

Table 6

Summary of analysis of variance for dry biomass of leaves (LDB), stems (SDB), and roots (RDB) and root/shoot ratio (R/S) of cherry tomato plants irrigated with saline water and subjected to different salicylic acid application methods, at 120 days after sowing

Source of variation	DF	Mean square			
		LDB	SDB	RDB	R/S
Salt level (SL)	1	728.80**	1145.97**	5447.79**	0.03*
Application method (AM)	3	712.71**	26.79^{ns}	1687.53**	0.26**
Interaction (NS × AM)	3	309.65*	21.14^{ns}	757.17**	0.01^{ns}
Residual	32	109.54	24.51	111.37	0.005
CV (%)		21.86	16.70	19.32	9.98

ns, **, * not significant and significant at $p \leq 0.01$ and at $p \leq 0.05$, respectively.

Irrigation with water with 2.6 dS m^{-1} salinity negatively affected the leaf (Figure 5A) and root (Figure 5B) dry biomass accumulation of the cherry tomatoes, regardless of SA application method. However, SA application via foliar spray stood out relative to the other methods, especially when the plants were irrigated with water with 2.6 dS m^{-1} salinity, as they showed increases of 52.4% (18.8 g $plant^{-1}$) in LDB and 26.1% (11.7 g $plant^{-1}$) in SDB compared with the control plants grown at the same salt level.

Fariduddin, Khan, Yusuf, Aafaqee and Khalil (2018) obtained similar results in an evaluation of the effect of foliar spray with SA (10^{-5} M) on tomato plants under salt stress (200 mM NaCl). The authors found that the application of SA provided an increase in the dry and fresh matter of both roots and shoots when compared with the control treatment. Salicylic acid is a natural phenolic compound that is involved in plant growth and in physiological processes that contribute to acclimatization to salt stress (A. A. R. Silva et al., 2021).

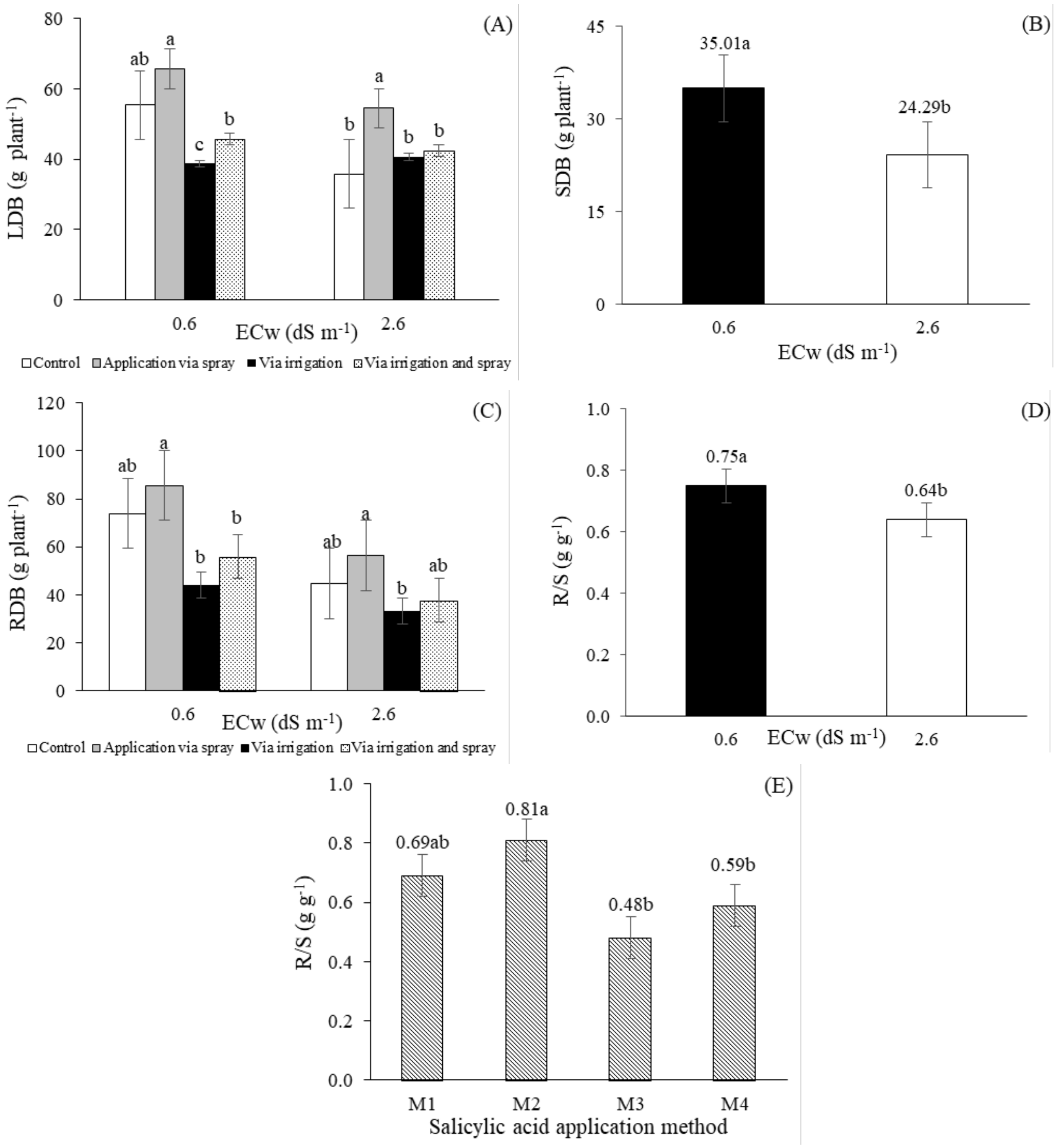

Figure 5. Dry biomass of leaves (LDB; A) and root (RDB; C) of tomato as a function of the interaction between the levels of electrical conductivity in irrigation water (ECw) and salicylic acid application methods, stem dry biomass (SDB; B) and root/shoot ratio (R/S; D) as a function of ECw, and R/S (E) as a function of salicylic acid application methods, at 100 days after sowing.

Means followed by different letters differ significantly between treatments by Tukey's test ($p \leq 5\%$). Vertical bars represent the standard error (n=5). M1 - control (no application); M2 - application via spray; M3 - via irrigation; M4 - via irrigation and spray.

For stem dry biomass (Figure 5B), the cherry tomato plants irrigated with water with 0.6 dS m^{-1} salinity stood out with the largest accumulation relative to those subjected to the ECw of 2.6 dS m^{-1}. Between the plants irrigated with low-salinity water (0.6 dS m^{-1}) and those irrigated with higher salinity (2.6 dS m^{-1}), a superiority of 10.72 g $plant^{-1}$ is observed in SDB for the former.

The decrease in the biomass accumulation in the plants irrigated with water with 2.6 dS m^{-1} salinity may be related to the high concentrations of salts present in the irrigation water, which caused ionic, osmotic, hormonal, and nutritional changes, thereby restricting water absorption and negatively affecting the growth and development of crops (Lima et al., 2016; Bezerra et al., 2018b).

In this study, spray application of SA acid mitigated the deleterious effects of salinity on *gs*, *E*, *A*, *iCE*, and *iWUE*. This response resulted in the accumulation of LDB and RDB. Increases in salinity hinder the absorption of water by the roots and, consequently, the entry of diluted SA in solution. However, the plants probably had a higher uptake of SA via foliar application. According to Farhadi and Ghassemi-Golezani (2020), foliar spray with SA is an easy and important way to improve the growth and yield of plants under salt stress. The enhancing effects of SA in different plant species under biotic and abiotic stresses may be due to its role in improving the plant's antioxidant capacity and protecting membranes against deterioration (Esan, Masisi, Dada, & Olaiya, 2017).

The root/shoot ratio of the cherry tomatoes (Figure 5D) differed statistically when the plant was irrigated with different salinity levels. Irrigation with water with 2.6 dS m^{-1} salinity caused a 14.7% decrease (0.11 g g^{-1}) in R/S compared with plants under irrigation with ECw 0.6 dS m^{-1}. The R/S of the cherry tomato plants (Figure 5E) cultivated without SA application (M1) and with foliarly sprayed with SA (M2) differed significantly relative to the other SA application methods. Application via irrigation (M3) and simultaneous use of irrigation and spraying (M4) did not differ statistically from each other.

Conclusions

Irrigation with water with 2.6 dS m^{-1} salinity negatively affects chlorophyll a fluorescence and the chlorophyll *a*, total chlorophyll, and carotenoid contents, besides inhibiting dry stem biomass production and the root/shoot ratio. The method of application of salicylic acid via foliar spray minimizes the deleterious effects of salt stress on gas exchange and chlorophyll b and induces greater accumulation of leaf and root dry biomass as well as increases the root/shoot ratio of cherry tomatoes, at 120 days after sowing.

References

Ahmad, P., Alyemeni, M. N., Ahanger, M. A., Egamberdieva, D., Wijaya, L., & Alam, P. (2018). Salicylic acid (SA) induced alterations in growth, biochemical attributes and antioxidant enzyme activity in faba bean (*Vicia faba* L.) seedlings under NaCl toxicity. *Russian Journal of Plant Physiology, 65*(1), 104-114. doi: 10.1134/S1021443718010132

Arnon, D. I. (1949). Copper enzymes in isolated chloroplasts: polyphenoloxidase in Beta vulgaris. *Plant Physiology, 24*(1), 1-15. doi: 10.1104/pp.24.1.1

Azevedo, L. C., Oliveira, A. C., Martins, I. C. S., Silva, V. L., & Ribeiro, C. S. (2018). Salinidade do solo em ambiente protegido. *Revista Campo Digital, 13*(1), 52-69.

Baker, N. (2008). Chlorophyll fluorescence: a probe of photosynthesis in vivo. *Annual Review of Plant Biology, 59*(1), 89-113. doi: 10.1146/annurev.arplant.59.032607.092759

Batista, M. C., Nascimento, R. D., Maia, S. O., Jr., Nascimento, E. C. S., Bezerra, C. V. C., & Lima, R. F. (2021). Physiology and production of cherry tomato cultivars in a hydroponic system using brackish water1. *Revista Brasileira de Engenharia Agrícola e Ambiental, 25*(4), 219-227. doi: 10.1590/1807-1929/agriambi.v25n4p219-227

Bezerra, I. L., Gheyi, H. R., Nobre, R. G., Lima, G. S. de, Santos, J. B. dos, & Fernandes, P. D. (2018a). Interaction between soil salinity and nitrogen on growth and gaseous exchanges in guava. *Revista Ambiente & Água, 13*(3), e2130. doi: 10.4136/ambi-agua.2130

Bezerra, I. L., Nobre, R. G., Gheyi, H. R., Souza, L. de P., Pinheiro, F. W. A., & Lima, G. S. de (2018b). Morphophysiology of guava under saline water irrigation and nitrogen fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental, 22*(1), 32-37. doi: 10.1590/1807-1929/agriambi.v22n1p32-37

Dias, A. S., Lima, G. S. de, Pinheiro, F. W. A., Gheyi, H. R., & Soares, L. A. A. (2019). Gas exchanges, quantum yield and photosynthetic pigments of West Indian cherry under salt stress and potassium fertilization. *Revista Caatinga, 32*(2), 429-439. doi: 10.1590/1983-21252019v32n216rc

Dias, A. S., Lima, G. S. de, Sá, F. V. S., Gheyi, H. R., Soares, L. A. A., & Fernandes, P. D. (2018). Gas exchanges and photochemical efficiency of West Indian cherry cultivated with saline water and potassium fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental, 22*(9), 628-633. doi: 10.1590/1807-1929/agriambi.v22n9p628-633

Esan, A. M., Masisi, K., Dada, F. A., & Olaiya, C. O. (2017). Comparative effects of indole acetic acid and salicylic acid on oxidative stress marker and antioxidant potential of okra (*Abelmoschus esculentus*) fruit under salinity stress. *Scientia Horticulturae, 216*(1), 278-283. doi: 10.1016/j.scienta.2017.01.007

Farhadi, N., & Ghassemi-Golezani, K. (2020). Physiological changes of Mentha pulegium in response to exogenous salicylic acid under salinity. *Scientia Horticulturae, 267*(1), e109325. doi: 10.1016/j.scienta.2020.109325

Fariduddin, Q., Khan, T. A., Yusuf, M., Aafaqee, S. T., & Khalil, R. R. A. E. (2018). Ameliorative role of salicylic acid and spermidine in the presence of excess salt in *Lycopersicon esculentum. Photosynthetica, 56*(3), 750-762. doi: 10.1007/s11099-017-0727-y

Ferreira, D. F. (2019). SISVAR: a computer analysis system to fixed effects split plot type designs. *Revista Brasileira de Biometria, 37*(4), 529-535. doi: 10.28951/rbb.v37i4.450

Figueiredo, F. R. A., Lopes, M. D. F. Q., Silva, R. T., Nóbrega, J. S., Silva, T. I., & Bruno, R. D. L. A. (2019). Respostas fisiológicas de mulungu submetida a estresse salino e aplicação de ácido salicílico. *Irriga, 24*(3), 662-675. doi: 10.15809/ irriga.2019v24n3p662-675

Gharbi, E., Lutts, S., Dailly, H., & Quinet, M. (2018). Comparison between the impacts of two different ways of applying salicylic acid on the responses of tomatoes (Solanum lycopersicum) to salinity. *Plant Signaling & Behavior, 13*(1), e1469361. doi: 10.1080/15592324.2018.1469361

Ghassemi-Golezani, K., Farhangi-Abriz, S., & Bandehagh, A. (2018). Salicylic acid and jasmonic acid alter physiological performance, assimilate mobilization and seed filling of soybean under salt stress. *Acta Agriculturae Slovenica, 111*(3), 597-607. doi: 10.14720/aas.2018.111.3.08

Guirra, K. S., Torres, S. B., Leite, M. S., Guirra, B. S., Nogueira, F. A., Neto, & Rêgo, A. L. (2020). Phytohormones on the germination and initial growth of pumpkin seedlings under different types of water. *Revista Brasileira de Engenharia Agrícola e Ambiental, 24*(12), 827-833. doi: 10.1590/1807-1929/agriambi.v24n12p827-833

Horváth, E., Csiszár, J., Gallé, Á., Poór, P., Szepesi, Á., & Tari, I. (2015). Hardening with salicylic acid induces concentration-dependent changes in abscisic acid biosynthesis of tomato under salt stress. *Journal Plant Physioly, 183*(1), 54-63. doi: 10.1016/j.jplph.2015.05.010

Instituto Brasileiro de Geografia e Estatística (2020). *Levantamento sistemático da produção agrícola.* Recuperado de https://biblioteca.ibge.gov.br/visualizacao/periodicos/2415/epag_2019_dez.pdf

Khan, M. I. R., Asgher, M., & Khan, N. A. (2014). Alleviation of salt-induced photosynthesis and growth inhibition by salicylic acid involves glycinebetaine and ethylene in mungbean (*Vigna radiata* L.). *Plant Physiology and Biochemistry, 80*(1), 67-74. doi: 10.1016/j.plaphy.2014.03.026

Lawlor, D. W., & Cornic, G. (2002). Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant, Cell & Environment, 25*(2), 275-294. doi: 10.1046/j.0016-8025. 2001.00814.x

Lima, G. S. de, Santos, J. B., Soares, L. A. A., Gheyi, H. R., Nobre, R. G., & Pereira, R. F. (2016). Irrigação com águas salinas e aplicação de prolina foliar em cultivo de pimentão 'All Big'. *Comunicata Scientiae, 7*(4), 513-522. doi: 10.14295/ CS.v7i4.1671

Londoño-Giraldo, L. M., Gonzalez, J., Baena, A. M., Tapasco, O., Corpas, E. J., & Taborda, G. (2020). Seleção de safras promissórias de tomate cereja selvagem por meio de parâmetros físico-químicos e teores de antioxidantes. *Bragantia, 79*(2), 169-179. doi: 10.1590/1678-4499.20190276

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae, 3*(2), e30. doi: 10.3390/ horticulturae3020030

Martínez-Cuenca, M. R., Pereira-Dias, L., Soler, S., López-Serrano, L., Alonso, D., Calatayud, A., & Díez, M. J. (2020). Adaptation to water and salt stresses of *Solanum pimpinellifolium* and *Solanum lycopersicum* var. cerasiforme. *Agronomy, 10*(8), e1169. doi: 10.3390/agronomy10081169

Matos, R. M., Silva, P. F., Dantas, J., Neto, Lima, A. S., Lima, V. L. A. de, & Saboya, L. M. F. (2021). Organic fertilization as an alternative to the chemical in cherry tomato growing under irrigation depths. *Bioscience Journal, 37*(1), e37006. doi: 10.14393/BJ-v37n0a2021-48270

Medeiros, J. F. D., Lisboa, R. D. A., Oliveira, M. D., Silva, M. J. D., Jr., & Alves, L. P. (2003). Caracterização das águas subterrâneas usadas para irrigação na área produtora de melão da Chapada do Apodi. *Revista Brasileira de Engenharia Agrícola e Ambiental, 7*(3), 469-472. doi: 10.1590/S1415-43662003000300010

Medeiros, P. R. F., Duarte, S. N., Uyeda, C. A., Silva, Ê. F. F., & Medeiros, J. F. (2012). Tolerância da cultura do tomate à salinidade do solo em ambiente protegido. *Revista Brasileira de Engenharia Agrícola e Ambiental, 16*(1), 51-55. doi: 10.1590/S1415-43662012000100007

Melo, A. S., Suassuna, J. F., Fernandes, P. D., Brito, M. E. B., Suassuna, A. F., & Aguiar, A. O., Netto. (2010). Crescimento vegetativo, resistência estomática, eficiência fotossintética e rendimento do fruto da melancieira em diferentes níveis de água. *Acta Scientiarum Agronomy, 32*(1), 73-79. doi: 10.4025/actasciagron.v32i1.2136

Novais, R. F., Neves, J. C. L., & Barros, N. F. (1991). Ensaio em ambiente controlado. In A. J. Oliveira (Ed.), *Métodos de pesquisa em fertilidade do solo* (Cap. 12, p. 189-253). Brasília: EMBRAPA-SEA.

Parvin, K., Ahamed, K. U., Islam, M. M., Haque, M. N., Hore, P. K., Siddik, M. A., & Roy, I. (2015). Reproductive behavior of tomato plant under saline condition with exogenous application of calcium. *Middle East Journal of Scientific Research, 23*(12), 2920-2926. doi: 10.5829/idosi.mejsr.2015.23.12.22 866

United States. (2014). Department of Agriculture. Keys to soil taxonomy. Califórnia: Natural Resources Conservation Service.

Poursakhi, N., Razmjoo, J., & Karimmojeni, H. (2019). Interactive effect of salinity stress and foliar application of salicylic acid on some physiochemical traits of chicory (*Cichorium intybus* L.) genotypes. *Scientia Horticulturae, 258*(1), e108810. doi: 10.1016/j.scienta.2019.108810

Reis, F. O., & Campostrini, E. (2011). Microaspersão de água sobre a copa: um estudo relacionado às trocas gasosas e à eficiência fotoquímica em plantas de mamoeiro. *Revista Brasileira de Agrociência, 17*(1), 284-295. doi: 10.18539/cast.v17i1.203

Richards, L. A. (1954). *Diagnosis and improvement of saline and alkali soils.* Washington, USA: Department of Agriculture.

Sá, F. V. S., Gheyi, H. R., Lima, G. S. de, Paiva, E. P., Moreira, R. C. L., & Silva, L. D. A. (2018). Water salinity, nitrogen and phosphorus on photochemical efficiency and growth of west indian cherry. *Revista Brasileira de Engenharia Agrícola e Ambiental, 22*(3), 158-163. doi: 10.1590/1807-1929/agriambi.v22 n3p158-163

Santos, C. M., Gonçalves, E. R., Endres, L., Gomes, T. C. A., Jadoski, C. J., Nascimento, L. A., & Santos, E. D. (2010). Atividade fotossintética em alface (*Lactuca sativa* L.) submetidas a diferentes compostagens de resíduos agroindustriais. *Pesquisa Aplicada & Agrotecnologia, 3*(3), 95-102.

Silva, A. R. A., Bezerra, F. M. L., Lacerda, C. F., Sousa, C. H. C., & Chagas, K. L. (2016). Pigmentos fotossintéticos e potencial hídrico foliar em plantas jovens de coqueiro sob estresses hídrico e salino. *Revista Agroambiente, 10*(4), 317-325. doi: 10.18227/1982-8470ragro.v10i4.3650

Silva, A. A. R., Lima, G. S. de, Azevedo, C. A. V. de, Gheyi, H. R., Souza, A. R. de, & Fernandes, P. D. (2021). Salicylic acid relieves the effect of saline stress on soursop morphysiology. *Ciência e Agrotecnologia, 45*(1), e007021. doi: 10.1590/1413-7054202145007021

Silva, M. M. P., Vasquez, H. M., Bressan-Smith, R., Silva, J. F. C., Erbesdobler, E. D. A., & Andrade, P. S. C., Jr. (2006). Eficiência fotoquímica de gramíneas forrageiras tropicais submetidas à deficiência hídrica. *Revista Brasileira de Zootecnia, 35*(1), 67-74. doi: 10.1590/S1516-35982006000100008

Souri, M. K., & Tohidloo, G. (2019). Effectiveness of different methods of salicylic acid application on growth characteristics of tomato seedlings under salinity. *Chemical and Biological Technologies in Agriculture, 6*(1), 1-7. doi: 10.1186/s40538-019-0169-9

Tatagiba, S. D., Moraes, G. A. B. K., Nascimento, K. J. T., & Peloso, A. F. (2014). Limitações fotossintéticas em folhas de plantas de tomateiro submetidas a crescentes concentrações salinas. *Engenharia na Agricultura, 22*(1), 138-149. doi: 10.13083/1414-3984.v22n02a05

Teixeira, P. C., Donagemma, G. K., Fontana, D., & Teixeira, W. G. (2017). *Manual de métodos de análise de solo* (3a ed.). Brasília: EMBRAPA Solos.

Vieira, I. G. S., Nobre, R. G., Dias, A. S., & Pinheiro, F. W. A. (2016). Cultivation of cherry tomato under irrigation with saline water and nitrogen fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental, 20*(1), 55-61. doi: 10.1590/1807-1929/agriambi.v20n1p55-61

Zanandrea, I., Lima, N. F., Turchetto, A. C., Braga, E. J. B., Peters, J. Á., & Bacarin, M. A. (2006). Efeito da salinidade sob parâmetros de fluorescência em *Phaseolus vulgaris. Current Agricultural Science and Technology, 12*(2), 157-161. doi: 10.18539/cast.v12i2.4512

Zörb, C., Geilfus, C. M., & Dietz, K. J. (2019). Salinity and crop yield. *Plant Biology, 21*(1), 31-38. doi: 10.1111/plb.12884