ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.6, e275968, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n6e275968

Original Article

Photosynthetic pigments, growth, and production of cherry tomato under salt stress and hydrogen peroxide[1]

Pigmentos fotossintéticos, crescimento, e produção de tomate cereja sob estresse salino e peróxido de hidrogênio

Jackson S. Nóbrega[2*], Maria A. Guedes[2], Geovani S. de Lima[2], Hans R. Gheyi[2], Lauriane A. dos A. Soares[3], Luderlândio de A. Silva[4], Saulo S. da Silva[4] & Larissa A. Brito[3]

[1] Research developed at Universidade Federal de Campina Grande, Centro de Ciências e Tecnologia Agroalimentar, Pombal, PB, Brazil
[2] Universidade Federal de Campina Grande/Programa de Pós-Graduação em Engenharia Agrícola, Campina Grande, PB, Brazil
[3] Universidade Federal de Campina Grande/Programa de Pós-Graduação em Horticultura Tropical/Unidade Acadêmica de Ciências Agrárias, Pombal, PB, Brazil
[4] Universidade Federal de Campina Grande/Programa de Pós-Graduação em Sistemas Agroindustriais, Pombal, PB, Brazil

HIGHLIGHTS:
Foliar application of H_2O_2 attenuates the effects of salt stress on cherry tomato growth under ECw of up to 3.1 dS m^{-1}.
H_2O_2 concentration of 45 µM increases chlorophyll contents in cherry tomato leaves.
Electrical conductivity of water above 1.41 dS m^{-1} reduces cherry tomato production.

ABSTRACT: Excess of salts in water and/or soil stands out as one of the stresses that compromise the development of crops, including cherry tomato, requiring the use of strategies that reduce salt stress effects, such as foliar application of hydrogen peroxide. Thus, the objective of this study was to evaluate the effect of foliar application of H_2O_2 on the contents of photosynthetic pigments, growth, and production of cherry tomato under irrigation water salinity. The design used was randomized blocks, in a 5 × 5 factorial scheme, with five values of electrical conductivity of water - ECw (0.3, 1.0, 1.7, 2.4, and 3.1 dS m^{-1}) and five concentrations of hydrogen peroxide - H_2O_2 (0, 15, 30, 45, and 60 µM). Application of hydrogen peroxide at concentration of 60 µM attenuated the deleterious effects of salt stress on the growth and number of leaves of cherry tomato up to ECw of 3.1 dS m^{-1}. Hydrogen peroxide concentration of 45 µM increased root dry mass, synthesis of chlorophyll b and total chlorophyll under electrical conductivity of water of 0.3 dS m^{-1} and synthesis of chlorophyll a up to ECw of 0.8 dS m^{-1}. Foliar application of 30 µM reduced the effects of salt stress on leaf, shoot and total dry mass accumulation up to ECw of 3.1 dS m^{-1}. Electrical conductivity of water from 1.41 dS m^{-1} reduced the production of cherry tomato.

Key words: *Solanum lycopersicum* L., acclimatization, elicitor, salinity

RESUMO: O excesso de sais na água e/ou no solo se destaca como um dos estresses que compromete o desenvolvimento das culturas, dentre elas o tomate cereja, sendo necessário o uso de estratégias que reduzam o efeito do estresse salino, como à aplicação foliar de peróxido de hidrogênio. Assim, o objetivo deste estudo foi avaliar o efeito da aplicação foliar de H_2O_2 sobre o teor de pigmentos fotossintéticos, crescimento e produção de tomate cereja sob salinidade da água de irrigação. O delineamento utilizado foi o de blocos casualizados, em esquema fatorial 5 × 5, sendo cinco valores de condutividade elétrica da água - CEa (0,3; 1,0; 1,7; 2,4 e 3,1 dS m^{-1}) e cinco concentrações de peroxido de hidrogênio – H_2O_2 (0; 15; 30; 45 e 60 µM). A aplicação de peróxido de hidrogênio na concentração de 60 µM atenuou o efeito deletério do estresse salino no crescimento em altura de plantas e no número de folhas de tomate cereja até a CEa de 3,1 dS m^{-1}. A concentração de 45 µM de peróxido de hidrogênio aumentou a fitomassa seca de raiz, a sintese de clorofila *b* e total sob água de condutividade elétrica de 0,3 dS m^{-1} e de clorofila *a* até a CEa de 0,8 dS m^{-1}. A aplicação foliar de 30 µM reduziu o efeito do estresse salino no acúmulo de fitomassa seca de folhas, da parte aérea e total até a CEa de 3,1 dS m^{-1}. A condutividade elétrica da água a partir de 1,41 dS m^{-1} reduziu a produção de tomate cereja.

Palavras-chave: *Solanum lycopersicum* L., aclimatação, elicitor, salinidade

• Ref. 275968 – Received 26 Jun, 2023
* Corresponding author - E-mail: jacksonnobrega@hotmail.com
• Accepted 17 Jan, 2024 • Published 20 Feb, 2024
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

This is an open-access article distributed under the Creative Commons Attribution 4.0 International License.

Introduction

The semi-arid region of the Brazilian Northeast is characterized by scarcity of water resources in terms of both quality and quantity, with irregular rainfall and high rates of evapotranspiration. Thus, the use of irrigation is a necessity of producers, who in many cases use water with high levels of salts, compromising crop development (Andrade et al., 2022).

Salt stress triggers a series of deleterious effects on plants, due to osmotic effects that limit their capacity to absorb water, ionic effects that result in specific ion toxicity and nutritional imbalance, and oxidative stress that leads to the formation of reactive oxygen species and degradation of enzymes and photosynthesizing pigments (Ramos et al., 2022a; Nóbrega et al., 2023).

Given the deleterious effects caused by salt stress on most cultivated species, there is a growing search for strategies capable of mitigating salt stress effects by inducing crop tolerance, among which the exogenous application of hydrogen peroxide (H_2O_2) stands out (Silva et al., 2021; Lacerda et al., 2022). In plants subjected to stress conditions, H_2O_2 application can induce cross-tolerance, through the signaling and modulation of antioxidant defense mechanisms, increasing the plant's tolerance to salt stress (Santos et al., 2019; Veloso et al., 2022; Silva et al., 2024).

Cherry tomato (*Solanum lycopersicum* L.) is a crop of high potential for exploitation and commercialization in the Brazilian Northeast, being widely used in the ornamentation of dishes and appetizers (Roque et al., 2022). The beneficial effect of foliar application of H_2O_2 on cherry tomatoes was observed by Guedes et al. (2023), who reported that foliar application of up to 25 μM attenuated the effect of salinity on the number and quality of fruits produced in a hydroponic system. Thus, it is necessary to develop strategies that enable cultivation with saline waters under the semi-arid conditions of northeastern Brazil. Given this context, the objective of this study was to evaluate the effect of foliar application of H_2O_2 on the contents of photosynthetic pigments, growth, and production of cherry tomato under irrigation water salinity.

Material and Methods

The experiment was conducted under field conditions from July 28 to October 27, 2022, at the Centro de Ciência e Tecnologia Agroalimentar (CCTA) of the Universidade Federal de Campina Grande (UFCG), located in the municipality of Pombal, Paraíba, Brazil, at the geographical coordinates 6º 46'13" S and 37°48'06" W, at an altitude of 193 m. The climate of the region is hot and dry semi-arid, with average annual evaporation of 2,000 mm and average annual rainfall of approximately 750 mm, according to Köppen's climate classification adapted to Brazil (Alvares et al., 2013). The data of maximum and minimum temperature, relative humidity, and precipitation during the experimental period are shown in Figure 1. Data were obtained daily with the aid of a digital thermo-hygrometer located in the center of the experimental area.

A randomized block design was used, in a 5 × 5 factorial scheme, whose treatments consisted of the combination of

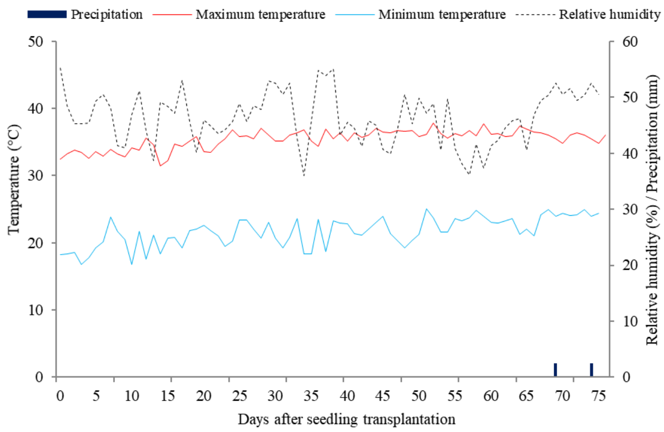


Figure 1. Data of maximum and minimum air temperature, relative air humidity, and precipitation during the experimental period (from July 27 to October 27, 2022)

two factors: five values of electrical conductivity of irrigation water - ECw (0.3, 1.0, 1.7, 2.4, and 3.1 dS m^{-1}) and five concentrations of hydrogen peroxide - H_2O_2 (0, 15, 30, 45, and 60 μM), with three replicates. The electrical conductivity values were based on a study carried out by Roque et al. (2022) with the cherry tomato crop (*Solanum lycopersicum* var. Cerasiforme), while the H_2O_2 concentrations were adapted from the study carried out by Dantas et al. (2022) with zucchini (*Cucurbita pepo* L.).

The seedlings were grown in polyethylene trays and transplanted into 20 L pots adapted as drainage lysimeters when they reached 10 cm in height. The lysimeters were filled with a 0.5 kg layer of crushed stone, followed by 20 kg of material from a sandy loam Neossolo Regolítico (Entisol - Psamment). The lysimeters were perforated at the base and connected to a 15-mm-diameter drain, positioned at the bottom of the lysimeter, wrapped with a non-woven geotextile (Bidim OP 30) to avoid clogging by soil material. Each drain was connected to a plastic bottle to collect drained water and determine water consumption by the plants. The soil used in the experiment came from the rural area of São Domingos de Pombal, PB, 0-20 cm layer, and its physical and chemical characteristics were obtained according to methodologies of Teixeira et al. (2017), as shown in Table 1.

Fertilization with NPK was carried out according to the recommendation of Trani et al. (2015) for the cultivation of table tomatoes, using urea as nitrogen source, with application of 38.9 g per plant (19.74 g of N), monoammonium phosphate as phosphorus source, with application of 20.35 g (12.44 g of P_2O_5 per plant), previously discounting the N supplied by this source, and potassium chloride as potassium source, with application of 65.94 g (39.56 g of K_2O per plant), starting at 12 days after transplanting, performed weekly via irrigation water.

The irrigation water of different electrical conductivity - ECw were prepared by dissolving sodium chloride (NaCl) in public-supply water of Pombal - PB, considering the relationship between ECw and salt concentration (Richards, 1954), according to Eq. 1:

$$C\left(\text{mg L}^{-1}\right) \approx 640 \times \text{ECw} \quad (1)$$

Table 1. Chemical and physical attributes of the soil (0-20 cm depth) used in the experiment, before the application of the treatments

Chemical attributes								
pH (H_2O) (1:2.5)	OM ($g\ kg^{-1}$)	P ($mg\ kg^{-1}$)	K^+ ($cmol_c\ kg^{-1}$)	Na^+ ($cmol_c\ kg^{-1}$)	Ca^{2+} ($cmol_c\ kg^{-1}$)	Mg^{2+} ($cmol_c\ kg^{-1}$)	Al^{3+} ($cmol_c\ kg^{-1}$)	H^+ ($cmol_c\ kg^{-1}$)
8.53	3.10	77.30	0.56	0.20	5.08	5.11	0	0
Chemical attributes				**Physical attributes**				
EC_{se} ($dS\ m^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	SAR_{se} ($(mmol\ L^{-1})^{0.5}$)	ESP (%)	Particle-size fraction ($g\ kg^{-1}$) Sand	Silt	Clay	Moisture ($dag\ kg^{-1}$) 33.42 kPa[1]	1519.5 kPa[2]
0.46	10.95	1.02	1.83	775.70	180.90	43.40	12.45	5.00

pH - Hydrogen potential, OM - Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 M KCl at pH 7.0; Na^+ and K^+ extracted with 1 M NH4OAc at pH 7.0; Al^{3+}+H^+ extracted with 0.5 M CaOAc at pH 7.0; EC_{se} - Electrical conductivity of saturation extract; CEC - Cation exchange capacity; SAR_{se} - Sodium adsorption ratio of saturation extract; ESP - Exchangeable sodium percentage; [1,2] referring to moisture contents in the soil corresponding to field capacity and permanent wilting point

where:

C - concentration of salts in irrigation water ($mg\ L^{-1}$); and

ECw - electrical conductivity of water ($dS\ m^{-1}$).

Prior to transplanting, the volume of water needed to raise soil moisture to the value corresponding to field capacity was determined. After transplanting, irrigation was performed daily at 5 p.m., applying in each lysimeter the volume corresponding to that obtained by the water balance, determined by Eq. 2:

$$VI = \frac{(Va - Vd)}{(1 - LF)} \quad (2)$$

where:

VI - volume of water to be used in the irrigation event (mL);

Va - volume applied in the previous irrigation event (mL);

Vd - volume drained in the previous irrigation event (mL); and

LF - leaching fraction of 0.15, applied every 15 days.

The desired concentrations of H_2O_2 were obtained by dilution in deionized water and applied by foliar spraying in the late afternoon (from 5 p.m.), performed manually with a spray bottle and fully wetting the leaves (abaxial and adaxial sides). The applications began 72 hours before the beginning of the application of saline water and were subsequently performed at 15-day intervals, until the plants began to flower. During H_2O_2 spraying, a plastic structure was used to prevent the solution from drifting onto neighboring plants, and an average volume of 15 mL was applied per plant.

At 45 days after transplanting (DAT), the contents of photosynthetic pigments and plant growth were evaluated. Contents of chlorophyll a, chlorophyll b, total chlorophyll and carotenoids were determined according to the methodology of Arnon (1949), using plant extracts collected from the blade of the third mature leaf from the apex, quantifying the values with a spectrophotometer at the absorbance wavelength (ABS) (470, 647 and 663), according to Eqs. 3, 4, 5, and 6:

$$\text{Chlorophyll a} = (12.25 \times ABS_{663}) - (2.79 \times ABS_{647}) \quad (3)$$

$$\text{Chlorophyll b} = (21.5 \times ABS_{647}) - (5.1 \times ABS_{663}) \quad (4)$$

$$\text{Total chlorophyll} = (7.15 \times ABS_{663}) + (18.71 \times ABS) \quad (5)$$

$$\text{Carotenoids} = \frac{\left[(1000 \times ABS_{470}) - (1.82 \times \text{Chl a}) - (85.02 \times \text{Chl b})\right]}{198} \quad (6)$$

The values obtained for the contents of chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids were expressed in $mg\ g^{-1}$ of fresh matter (FM).

Growth variables evaluated were the number of leaves (NL), determined by counting fully formed leaves; plant height (PH), obtained by taking as reference the distance from the plant collar to the insertion of the apical meristem; stem diameter (SD), measured at 5 cm from the plant collar with a digital caliper; and the height/diameter ratio of cherry tomato plants.

The production components of cherry tomato were determined by evaluating the number of fruits per plant (NFP), total fruit fresh mass (TFFM), and average fruit weight (AFW). NFP was obtained by counting all fruits produced per plant. TFFM was determined on a precision balance. AFW was determined as the ratio between TFFM and NFP. Harvest was carried out when the fruits showed color varying from light green to bright red (Monteiro et al., 2018) and began at 45 DAT, extending to 75 DAT.

At the end of the experiment at 75 DAT, the plants were removed from the lysimeters and separated into roots, stem, and leaves, which were placed in kraft paper bags and dried in a forced air circulation oven at 65 °C until reaching constant weight. Then, the samples were weighed on a balance with 0.01 g precision to obtain root dry mass, stem dry mass and leaf dry mass. Shoot dry mass was obtained by summing stem dry mass and leaf dry mass, while the total dry mass of cherry tomato was determined by summing all the biomass values.

The data obtained were subjected to the normality test (Shapiro-Wilk) and then to analysis of variance by the F test at $p \leq 0.01$ and $p \leq 0.05$. Polynomial regression analysis was applied, and trend lines were presented only for the variables with coefficient of determination (R^2) > 0.6, for prognostic purposes. The statistical program Sisvar® version 5.6 was used to perform the analysis (Ferreira, 2019).

Results and Discussion

The interaction between irrigation water electrical conductivity values and H_2O_2 concentrations significantly ($p \leq 0.01$) affected the contents of chlorophyll a, chlorophyll b, total chlorophyll and carotenoids of cherry tomato plants (Table 2).

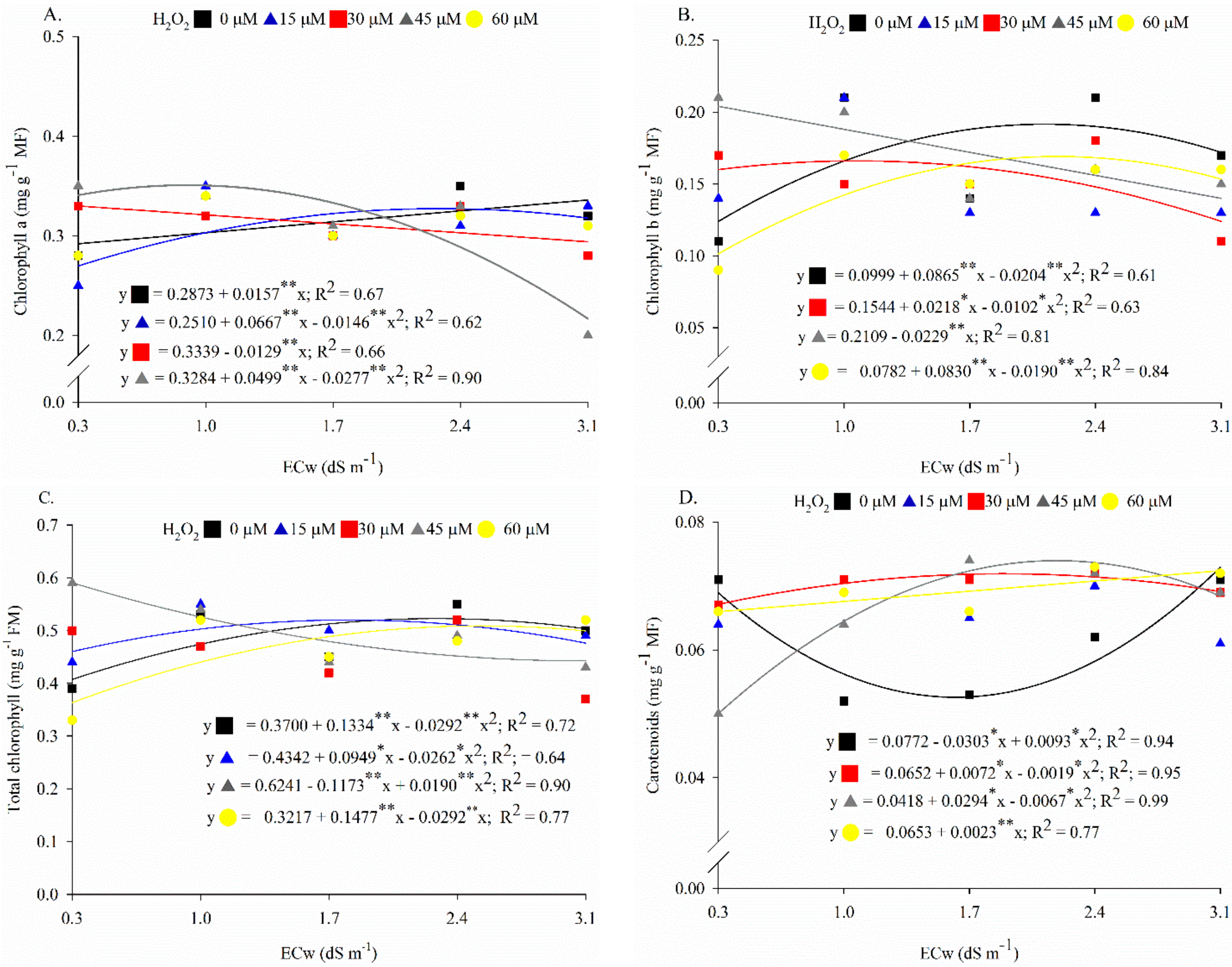
Application of H_2O_2 reduced the effect of salt stress on the synthesis of photosynthetic pigments of cherry tomato. For

Table 2. Summary of the analysis of variance for chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll (Chl T) and carotenoids (Car) of cherry tomato plants, at 45 days after transplanting subjected to electrical conductivity of irrigation water (ECw) values and hydrogen peroxide (H_2O_2) concentrations

Variation sources	DF	Mean squares			
		Chl a	Chl b	Chl T	Car
ECw values (ECw)	4	0.0052**	0.0079**	0.020**	0.00014**
Linear regression	1	0.000083ns	0.00032ns	0.00029ns	0.00044**
Quadratic regression	1	0.0050**	0.0014*	0.0023ns	0.000001ns
Hydrogen peroxide (H_2O_2)	4	0.00037ns	0.0025**	0.0048**	0.00017**
Linear regression	1	0.000021ns	0.00016ns	0.00036ns	0.00037**
Quadratic regression	1	0.00085ns	0.00009ns	0.000017ns	0.000086*
Interaction (ECw × H_2O_2)	16	0.00038**	0.0029**	0.012**	0.00012**
Blocks	2	0.00021ns	0.00012ns	0.0043**	0.000025ns
Residual	48	0.00030	0.00028	0.00075	0.000014
CV (%)		5.59	10.9	5.79	5.62

DF - Degrees of freedom; CV - Coefficient of variation; (**) significant at p ≤ 0.01; (*) significant at p ≤ 0.05; (ns) not significant

the chlorophyll a contents (Figure 2A), the highest estimated value (0.35 mg g^{-1} FM) was obtained in plants subjected to ECw of 0.8 dS m^{-1} and 45 μM of H_2O_2. In plants grown under ECw of 3.1, 2.3 and 0.3 dS m^{-1}, the maximum estimated values of 0.33, 0.32 and 0.33 mg g^{-1} FM were achieved under foliar application of 0, 15 and 30 μM of H_2O_2, respectively. On the other hand, in plants subjected to electrical conductivity of water of 1.9 dS m^{-1} the maximum value (0.32 mg g^{-1} FM) was achieved under application of 60 μM of H_2O_2 ($y = 0.2780 + 0.0454^{**}x - 0.0117^{**}x^2$, $R^2 = 0.56$). The beneficial effect of H_2O_2 at adequate concentrations on chlorophyll a contents is associated with its physiological role in signaling defense mechanisms and cellular homeostasis in plants subjected to stress conditions (Veloso et al., 2022).



*, ** - significant at p ≤ 0.05 and p ≤ 0.01 by the F test, respectively

Figure 2. Contents of chlorophyll a, chlorophyll b, total chlorophyll (A, B, and C, respectively), and carotenoids (D) of cherry tomato plants, at 45 days after transplanting as a function of electrical conductivity of irrigation water - ECw and hydrogen peroxide concentrations

Chlorophyll b and total chlorophyll contents were higher (0.20 and 0.59 mg g^{-1} FM) in plants subjected to irrigation water electrical conductivity of 0.3 dS m^{-1} and H_2O_2 concentration of 45 μM, respectively (Figure 2B and 2C). The increase in chlorophyll contents occurs due to the metabolic changes triggered by H_2O_2, stimulating the activity of antioxidant enzymes that reduce the degradation of photosynthetic pigments (Ashraf et al., 2015). However, it was observed that the increase in H_2O_2 concentration of 60 μM led to the lowest values (0.10 and 0.36 mg g^{-1} FM) in plants irrigated with water of 0.3 dS m^{-1}. The occurrence of this effect may be due to the fact that H_2O_2 is a reactive species of oxygen, which in excess can cause oxidative stress and even intensify the damaging effect of salinity. This fact has been observed by Andrade et al. (2022) in yellow passion fruit (*Passiflora edulis* f. *flavicarpa* Dreneger) and by Capitulino et al. (2023) in soursop (*Annona muricata* L.).

The H_2O_2 concentration of 15 μM ($y = 0.0609 + 0.0069^*x - 0.0020^*x^2$, $R^2 = 0.57$) attenuated the effect of electrical conductivity of water on carotenoid contents, with the highest value (0.10 mg g^{-1} FM) obtained under electrical conductivity of 3.1 dS m^{-1} (Figure 2D). On the other hand, irrigation with ECw of 0.3 dS m^{-1} and foliar application of 45 μM resulted in the lowest value of carotenoids (0.05 mg g^{-1} FM). At H_2O_2 concentrations of 0 and 60 μM, the highest values of carotenoids (0.073 and 0.072 mg g^{-1} FM) were obtained in plants subjected to ECw of 3.1 dS m^{-1}, whereas the H_2O_2 concentrations of 30 and 45 μM resulted in values of 0.072 and 0.074 mg g^{-1} FM under ECw of 1.9 and 2.2 dS m^{-1}, respectively. This behavior indicates that H_2O_2 application induced the production of carotenoids in cherry tomato plants, standing out as a mechanism to prevent photoinhibition due to salt stress, improving the acclimatization of plants and reducing oxidative stress (Andrade et al., 2022).

The occurrence of beneficial effect of H_2O_2 application on the synthesis of photosynthetic pigments in plants under salt stress conditions has been reported in other species, such as passion fruit, for which Ramos et al. (2022a) found that the application of 15 μM of H_2O_2 attenuated the effect of electrical conductivity up to 3.0 dS m^{-1} and increased the contents of chlorophylls and carotenoids. Aragão et al. (2023) also found that the concentration of 15 μM increased the synthesis of photosynthetic pigments in bell pepper plants up to ECw of 1.4 dS m^{-1}.

The interaction between electrical conductivity of water and H_2O_2 concentrations significantly influenced ($p \leq 0.01$) all growth variables analyzed (Table 3).

Hydrogen peroxide application increased the growth in height of cherry tomato plants, with the highest value of 88 cm obtained under irrigation with ECw of 3.1 dS m^{-1} and H_2O_2 concentration of 60 μM, while the lowest value (66.4 cm) was obtained under 30 μM of H_2O_2 and electrical conductivity of 3.1 dS m^{-1}. At H_2O_2 concentrations of 0 and 15 μM ($y_{15\,\mu M} = 60.4981 + 15.6292^*x - 3.7901^*x^2$, $R^2 = 0.56$), the highest estimated values of 81.7 and 76.6 cm were reached in plants subjected to ECw of 3.1 and 2.1 dS m^{-1}, respectively. For the concentrations of 30 μM ($y_{30\,\mu M} = 67.4138 + 11.3300^*x - 3.7609^*x^2$, $R^2 = 0.51$) and 45 μM, the highest values of 76.0 and 87.0 cm were obtained in plants subjected to ECw of 1.5 dS m^{-1} (Figure 3A).

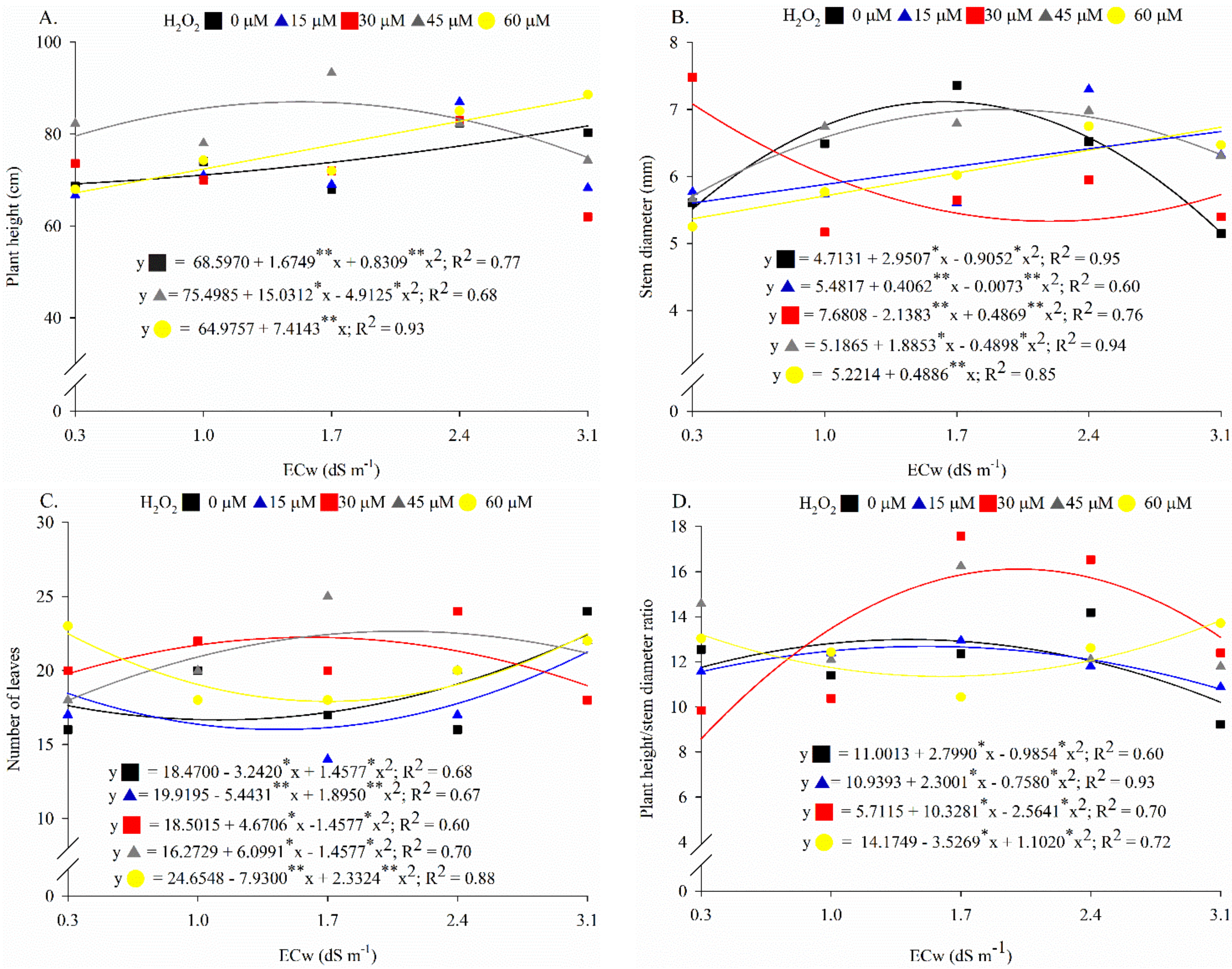
Thus, it is possible to highlight that the H_2O_2 concentrations of 45 and 60 μM promoted the highest growth in height of cherry tomato plants under water salinity conditions, possibly because H_2O_2 is involved in the mechanisms of enzymatic defense and contributes to reducing osmotic and ionic effects, enabling greater absorption of water and nutrients by plants, in addition to reducing the accumulation of reactive oxygen species, avoiding oxidative stress (Capitulino et al., 2023).

For stem diameter (Figure 3B), the largest increase occurred in plants subjected to ECw of 1.6 dS m^{-1} and H_2O_2 concentration of 0 μM (control), with the maximum estimated value of 7.12 mm. However, as the ECw increased, reductions were observed, with the lowest value of 5.16 mm in plants grown under irrigation water electrical conductivity of 3.1 dS m^{-1} and H_2O_2 concentration of 0 μM. At H_2O_2 concentrations of 15 and 60 μM, the highest values (6.7 mm for both) occurred in plants subjected to ECw of 3.1 dS m^{-1}. At concentrations of 30 and 45 μM, the highest values (7.08 and 7.0 mm) were obtained under ECw of 0.3 and 1.9 dS m^{-1}, respectively. This behavior indicates that H_2O_2 application accentuated the effect of salt stress, reducing stem diameter when compared to plants that did not receive H_2O_2 application. This reduction in diameter caused by salt stress occurs due to changes in the physiological processes of the plant, including cell expansion and elongation (Nóbrega et al., 2022).

Table 3. Summary of the analysis of variance for plant height (PH), stem diameter (SD), number of leaves per plant (NL), plant height/stem diameter ratio (PH/SD), root (RDM), stem (STDM), leaf (LDM), shoot (SHDM), and total (TDM) dry mass per plant of cherry tomato, at 45 days after transplanting subjected to electrical conductivity of irrigation water (ECw) values and hydrogen peroxide (H_2O_2) concentrations

Variation sources	DF	Mean squares								
		PH	SD	NL	PH/SD	RDM	STDM	LDM	SHDM	TDM
ECw values (ECw)	4	618.23**	0.58^{ns}	36.18**	8.99**	26.61**	13.38**	3.84**	12.32**	69.34**
Linear regression	1	816.66**	1.60*	34.56**	2.33^{ns}	35.11**	38.99**	4.81**	16.39**	99.51**
Quadratic regression	1	7.24^{ns}	0.20^{ns}	47.61**	0.83^{ns}	60.96**	12.32**	3.00*	27.50**	170.37**
Hydrogen peroxide (H_2O_2)	4	93.29**	0.34^{ns}	17.75**	3.99^{ns}	8.63**	8.67**	10.45**	32.12**	64.37**
Linear regression	1	81.40*	0.007^{ns}	52.80**	1.22^{ns}	6.00**	15.81**	0.039^{ns}	14.27**	38.79**
Quadratic regression	1	15.74^{ns}	0.15^{ns}	0.23^{ns}	2.82^{ns}	12.40**	12.25**	29.98**	80.58**	156.22**
Interaction (SL × H_2O_2)	16	381.69**	2.10**	28.32**	20.22**	4.43**	6.74**	19.25**	35.66**	41.01**
Blocks	2	43.22^{ns}	0.44^{ns}	6.09^{ns}	3.17^{ns}	0.078^{ns}	1.38^{ns}	1.20^{ns}	1.60^{ns}	1.01^{ns}
Residual	48	20.12	0.28	3.02	2.28	0.51	0.57	0.61	1.39	1.66
CV (%)		5.96	8.71	8.95	12.0	22.3	10.2	10.0	7.80	7.44

DF - Degrees of freedom; CV - Coefficient of variation; (**) significant at $p \leq 0.01$; (*) significant at $p \leq 0.05$; (ns) not significant



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

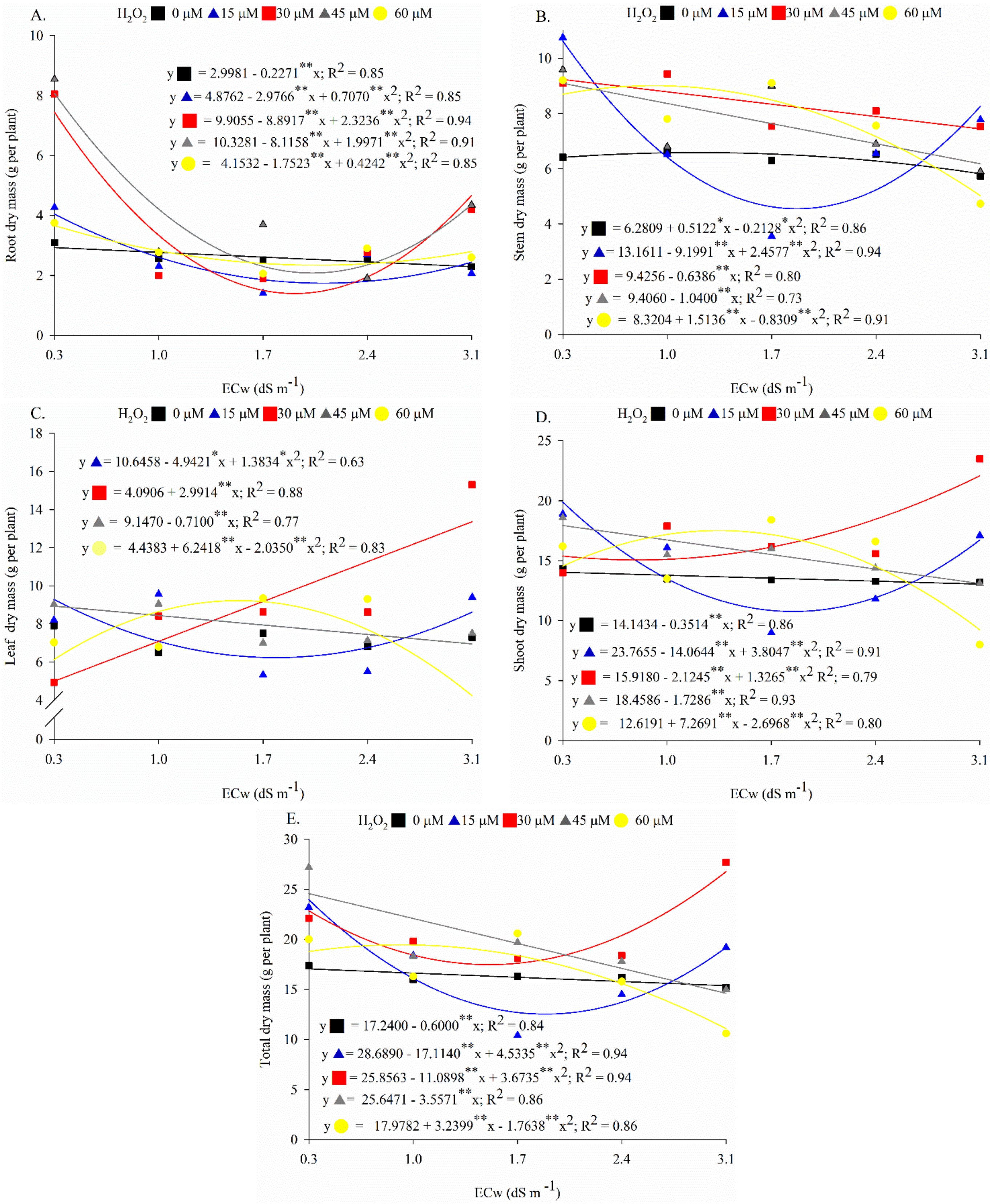
Figure 3. Plant height (A), stem diameter (B), number of leaves (C), and plant height/stem diameter ratio (D) of cherry tomato plants, at 45 days after transplanting as a function of electrical conductivity of irrigation water (ECw) values and hydrogen peroxide (H_2O_2) concentrations

The number of leaves was higher in plants that received H_2O_2 application at concentrations of 45 µM and ECw value of 2.1 dS m^{-1}, and 60 µM under the ECw values of 0.3 and 3.1 dS m^{-1}, with 23 leaves in both cases (Figure 3C). Hydrogen peroxide concentrations of 0, 15 and 30 µM promoted the maximum estimated values of 22 and 20 leaves in plants subjected to ECw of 3.1 and 1.6 dS m^{-1}, respectively. Contrary to what was observed for the growth in stem diameter (Figure 3B), the increase in the number of leaves is an indication that the application of H_2O_2 mitigated the effect of salt stress, probably due to its function in the signaling of enzymes that regulate the plant's defense system, increasing tolerance to salt stress (Aragão et al., 2023).

The highest plant height/stem diameter ratio (16.1) occurred in plants subjected to water salinity of 2.0 dS m^{-1} and H_2O_2 concentration of 30 µM (Figure 3D). At concentrations of 0 and 15 µM, the highest values (12.9 and 12.6) were obtained in plants subjected to irrigation water electrical conductivity of 1.4 dS m^{-1}. At H_2O_2 concentrations of 45 µM ($y_{45\mu M} = 13.6169 + 1.1620{*}x - 0.5758{*}x^2$, $R^2 = 0.52$) and 60 µM, the highest values of PH/SD ratio (14.2 and 13.0) were obtained under ECw of 1.0 and 0.3 dS m^{-1}, respectively. The increase in plant height/stem diameter ratio promoted by H_2O_2 concentrations is an indication that its application improves the tolerance of cherry tomato probably due to the contribution of metabolites and antioxidants (Silva et al., 2024).

Beneficial effect of exogenous application of H_2O_2 on plant growth under salt stress conditions has also been reported by other authors, such as Santos et al. (2019), who evaluated melon under concentration of 15 mM. Capitulino et al. (2023) found that the concentration of 30 µM attenuates the effects of salinity on soursop, and Aragão et al. (2023), in bell pepper, observed a mitigating effect at the concentration of 15 µM.

The dry mass production of cherry tomato plants was stimulated by H_2O_2 application under salt stress conditions. For root dry mass (Figure 4A), the highest value (8.07 g per plant) was obtained in plants subjected to ECw of 0.3 dS m^{-1} and H_2O_2 concentration of 45 µM, with a reduction of 46% when compared with the values obtained in plants cultivated under ECw of 3.1 dS m^{-1}. At the other H_2O_2 concentrations,



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

Figure 4. Root (A), stem (B), leaf (C), shoot (D) and total (E) dry mass of cherry tomato plants, at 75 days after transplantation as a function of electrical conductivity of irrigation water (ECw) values and hydrogen peroxide (H_2O_2) concentrations

the highest RDM values were also observed under the lowest ECw (0.3 dS m^{-1}), with reductions of 21.7, 39.6, 37.2, and 13.7% compared to plants irrigated with water of highest electrical conductivity (3.1 dS m^{-1}) at H_2O_2 concentrations of 0, 15, 30, and 60 μM, respectively. Hydrogen peroxide is a signaling molecule of the defense system, which induces the production of organic compounds and proteins, reducing the oxidative effect of reactive oxygen species (Khan et al., 2018), which may have enabled the development of the root system of cherry tomato plants.

For stem dry mass (Figure 4B), the highest estimated values were reached in plants grown under ECw of 0.3 dS m^{-1} and H_2O_2 concentrations of 15, 30 and 45 µM (10.6, 9.23 and 9.31 g per plant). Foliar application of 60 µM of H_2O_2 promoted the maximum value (9.0 g per plant) in plants grown under estimated ECw of 0.9 dS m^{-1}, whereas plants grown under foliar application of 0 µM obtained the maximum value (6.59 g per plant) under irrigation with water of electrical conductivity of 1.2 dS m^{-1}. When comparing the maximum values obtained, it is possible to observe increments of 37.8, 28.6, 29.2, and 26.8% at the concentrations of 15, 30, 45, and 60 µM, respectively, compared to the control (0 µM), indicating that H_2O_2 promoted greater growth of cherry tomato plants subjected to salt stress. It is noteworthy that H_2O_2 concentration of 15 µM caused a marked reduction in plants subjected to ECw of 1.7 dS m^{-1}. The fact that H_2O_2 acts on the antioxidant defense mechanisms of plants, from the signaling of enzymes, induces tolerance to salinity (Lacerda et al., 2022), allowing greater capacity to promote cell expansion and division, resulting in increased stem biomass.

For leaf, shoot, and total dry mass of cherry tomato plants (Figures 4C, 4D and 4E), the highest values (13.4, 22.1, and 26.8 g per plant) were obtained under irrigation with water of electrical conductivity of 3.1 dS m^{-1} and H_2O_2 concentration of 30 µM, whereas the lowest values (4.23, 9.22, and 11.1 g per plant, respectively) were obtained in plants subjected to ECw of 3.1 dS m^{-1} and H_2O_2 concentration of 60 µM. The increase in biomass accumulation may be associated with the fact that H_2O_2 acts in the regulation of plant growth under stress conditions, increasing cell wall strength and resistance, and favoring cell expansion processes (Ramos et al., 2022b).

There was significant effect of the interaction between water electrical conductivity values and H_2O_2 concentrations for the average fruit weight ($p \le 0.05$), while water salinity significantly ($p \le 0.05$) influenced the number of fruits per cherry tomato plant (Table 4). Total fruit fresh mass was significantly affected by the single factors electrical conductivity values ($p \le 0.01$) and H_2O_2 concentrations ($p \le 0.05$).

Table 4. Summary of the analysis of variance for number of fruits per plant (NFP), average fruit weight (AFW), and total fruit fresh mass (TFFM) of cherry tomato, harvested in the period from 45 to 75 days after transplanting subjected to electrical conductivity of irrigation water (ECw) values and hydrogen peroxide (H_2O_2) concentrations

Variation sources	DF	Mean squares		
		NFP	AFW	TFFM
ECw values (ECw)	4	55.05^{*}	11.75^{**}	4028.02^{**}
Linear regression	1	63.37^{*}	37.88^{**}	3971.99^{**}
Quadratic regression	1	90.02^{*}	3.38^{ns}	105.88^{ns}
Hydrogen peroxide (H_2O_2)	4	11.38^{ns}	3.80^{ns}	1704.91^{*}
Linear regression	1	6.61^{ns}	6.00^{ns}	1573.47*
Quadratic regression	1	0.86^{ns}	7.59^{ns}	717.09^{ns}
Interaction (ECw × H_2O_2)	16	17.44^{ns}	4.24^{*}	638.01^{ns}
Blocks	2	13.48^{ns}	0.65^{ns}	648.25^{ns}
Residual	48	11.06	2.00	392.29
CV (%)		35.7	23.1	32.4

DF - Degrees of freedom; CV - Coefficient of variation; (**) significant at $p \le 0.01$; (*) significant at $p \le 0.05$; (ns) not significant

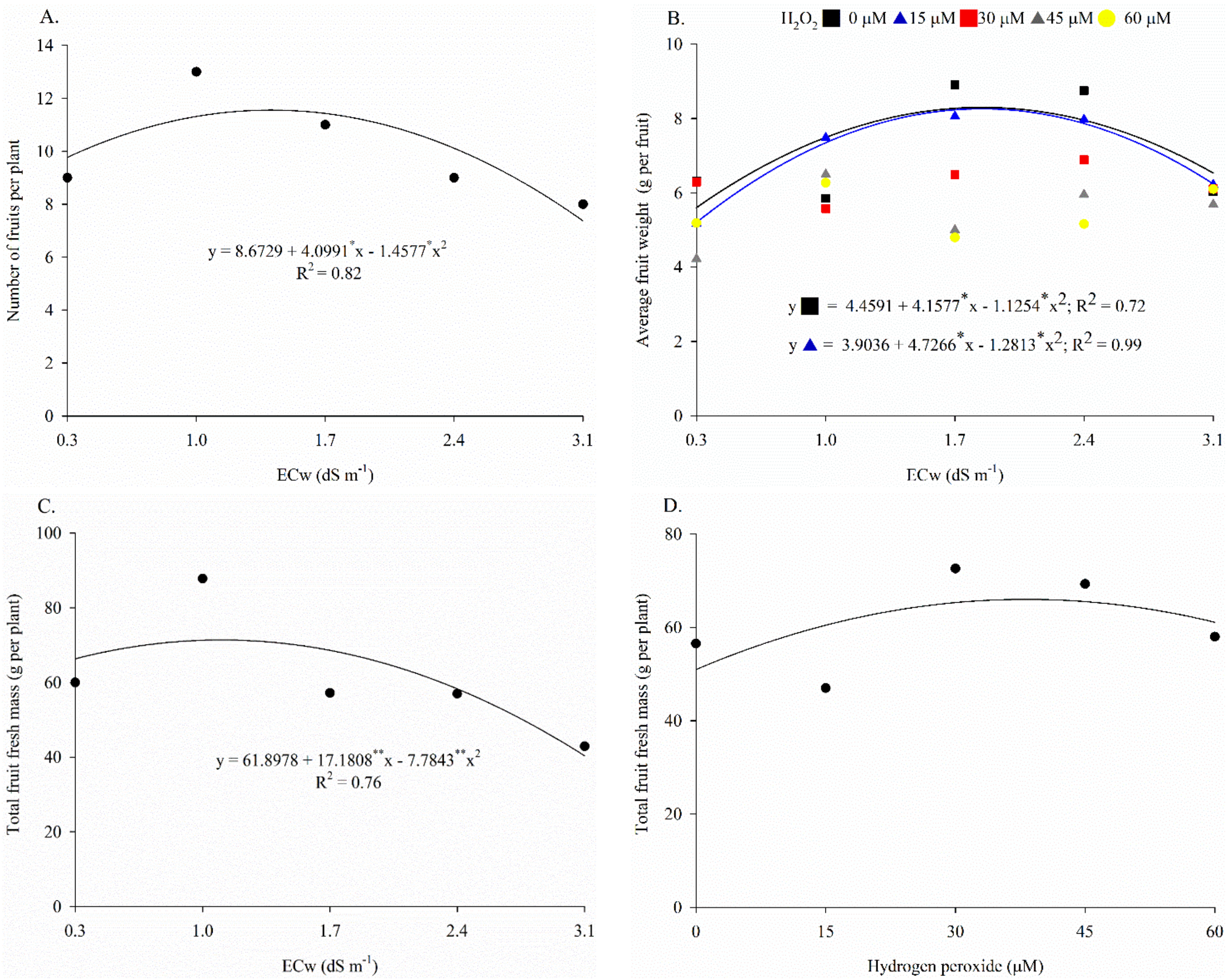
The number of fruits per plant was described by the quadratic model, with the highest value (12 fruits per plant) obtained in plants grown under ECw of 1.4 dS m^{-1} (Figure 5A), followed by decreases with increasing salinity, reaching 36.2% when compared with the values obtained at ECw of 3.1 dS m^{-1}. It should be noted that the values obtained in this study are well below the average values of the crop's production capacity, which is due to the environmental conditions during the flowering and fruiting stages, when high temperatures associated with low relative humidity may have intensified the effect of salinity, causing the abortion of flowers and fruits, as highlighted by Roque et al. (2022) in a study with cherry tomato.

For average fruit weight (Figure 5B), the highest values (8.28 and 8.26 g per fruit) were achieved in plants subjected to irrigation water electrical conductivity of 1.8 dS m^{-1} and H_2O_2 concentrations of 0 and 15 µM, respectively (Figure 5A). Plants grown under foliar application of 45 µM ($y_{45µM} = 4.1593 + 1.6449^{*}x - 0.3834^{*}x^2$, $R^2 = 0.58$) obtained the highest value (5.92 g per fruit) under ECw of 2.1 dS m^{-1}. The AFW data of plants subjected to H_2O_2 concentrations of 30 and 60 µM were not satisfactorily described by any regression model tested ($y_{30µM} = 5.8603 + 0.4579^{*}x - 0.0948^{*}x^2$, $R^2 = 0.35$; $y_{60µM} = 5.7631 - 0.6668^{*}x + 0.2259^{*}x^2$, $R^2 = 0.36$), respectively.

From the results it is possible to verify that H_2O_2 application accentuated the effect of salt stress on the production of cherry tomato, reducing the average fruit weight when plants were subjected to different concentrations and compared to the control (0 µM). By intensifying the deleterious effect of salinity, H_2O_2 causes oxidative stress due to accumulation of reactive oxygen species, reducing plant production (Dantas et al., 2022).

For the total fruit fresh mass, it is possible to observe that the salinity of irrigation water caused reductions, with the highest estimated value (71.4 g per plant) obtained in plants subjected to ECw of 1.1 dS m^{-1}, reaching a reduction of 43.5% (31.03 g per plant), when compared with the values obtained under irrigation water electrical conductivity of 3.1 dS m^{-1} (Figure 5C). This effect is an indication that salt stress caused a reduction in the number of fruits and in their size, resulting in low values of total fruit fresh mass. Reduction in cherry tomato production due to salt stress was also found by Agius et al. (2022), but the authors point out that salinity promoted improvements in the physicochemical quality of the fruits.

Regarding the effect of H_2O_2 concentrations on the total fresh mass of cherry tomato fruits ($y = 50.9429 + 0.7023^{*}x - 0.0081^{*}x^2$, $R^2 = 0.58$), it is possible to highlight that the highest value (66.2 g per plant) was obtained in plants subjected to a concentration of 43 µM, representing an increase of 23% when compared to the values of plants that did not receive foliar application of H_2O_2. This effect may be associated with a positive effect of H_2O_2 on the development and biomass production of shoots, increasing the availability of organic solutes to the fruits, resulting in an increase in the total fresh mass of cherry tomato fruits. This was observed in potato



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

Figure 5. Number of fruits per plant of cherry tomato as a function of electrical conductivity of irrigation water (ECw) (A), average fruit weight as a function of the interaction between ECw and hydrogen peroxide (H_2O_2) concentrations (B), and total fruit fresh mass (C and D) as a function of ECw (C) and H_2O_2 concentrations (D), for fruits harvested in the period from 45 to 75 days after transplantation

production by Elhady et al. (2021), who found that H_2O_2 application promoted increments in water productivity and tuber yield.

Conclusions

1. Electrical conductivity of irrigation water above 1.4 dS m^{-1} compromises the growth, photosynthetic pigments, and production of cherry tomatoes.

2. Application of hydrogen peroxide at concentration of 60 µM attenuates effects of salt stress on the growth in plant height and number of leaves of cherry tomato up to the electrical conductivity of 3.1 dS m^{-1}, at 45 days after transplanting.

3. Foliar application of hydrogen peroxide up to 45 µM increases dry mass production and chlorophyll synthesis under water salinity of 0.3 and 0.8 dS m^{-1}, respectively. The production of carotenoids is stimulated by the application of 15 µM of hydrogen peroxide up to electrical conductivity of irrigation water of 3.1 dS m^{-1}.

Literature Cited

Agius, C.; Von Tucher, S.; Rozhon, W. The effect of salinity on fruit quality and yield of cherry tomatoes. Horticulturae, v.8, e59, 2022. https://doi.org/10.3390/horticulturae8010059

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. M.; Leonardo. J.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Andrade, E. M. G.; Lima, G. S. de; Lima, V. L. A. de; Silva, S. S. da; Dias, A. S.; Gheyi, H. R. Hydrogen peroxide as attenuator of salt stress effects on the physiology and biomass of yellow passion fruit. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.571-578, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n8p571-578

Aragão, J.; Lima, G. S. de; Lima, V. L. A. de; Silva, A. A. R. de; Santos, L. F. S.; Dias, M. dos S.; Arruda, T. F. de L.; Souza, A. R. de; Soares, L. A. dos A. Hydrogen peroxide in the mitigation of salt stress in bell pepper. Semina: Ciências Agrárias, v.44, p.217-238, 2023. http://doi.org/10.5433/1679-0359.2022v44n1p217

Arnon, D. I. Copper enzymes in isolated cloroplasts: polyphenoloxidases in *Beta vulgaris*. Plant Physiology, v.24, p.1-15, 1949. https://doi.org/10.1104%2Fpp.24.1.1

Ashraf, M. A.; Rizwan, R.; Hussain, I.; Haider, M. Z.; Parveen, S.; Sajid, M. A. Hydrogen peroxide modulates antioxidant system and nutrient relation in maize (*Zea mays* L.) under water-deficit conditions. Archives of Agronomy and Soil Science, v.61, p.507-523, 2015. https://doi.org/10.1080/03650340.2014.938644

Capitulino, J. D.; Lima, G. S. de; Azevedo, C. A. V. de; Silva, A. A. R. da; Arruda, T. F. de L.; Soares, L. A. dos A.; Gheyi, H. R.; Fernandes, P. D.; Farias, M. S. S.; Silva, F. A. da; Dias, M. dos S. Influence of foliar application of hydrogen peroxide on gas exchange, photochemical efficiency, and growth of soursop under salt stress. Plants, v.12, p.1-17, 2023. https://doi.org/10.3390/plants12030599

Dantas, M. V.; Lima, G. S. de; Gheyi, H. R.; Pinheiro, F. W. A.; Silva, P. C. C.; Soares, L. A. dos A. Gas exchange and hydroponic production of zucchini under salt stress and H_2O_2 application. Revista Caatinga, v.35, p.436-439, 2022. http://dx.doi.org/10.1590/1983-21252022v35n219rc

Elhady, S. A. A.; El-Gawad, H. G. A.; Ibrahim, M. F. M.; Mukherjee, S.; Elkelish, A.; Azab, E.; Gobouri, A. A.; Farag, R.; Abrahim, H. A.; El-Azm, N. A. Hydrogen Peroxide supplementation in irrigation water alleviates drought stress and boosts growth and productivity of potato plants. Sustainability, v.13, e899, 2021. https://doi.org/10.3390/su13020899

Ferreira, D. F. Sisvar: a computer analysis system to fixed effects split plot type designs. Revista Brasileira de Biometria, v.37, p.529-535, 2019. https://doi.org/10.28951/rbb.v37i4.450

Guedes, M. A.; Silva, A. A. R. da; Lima, G. S. de; Gheyi, H. R.; Soares, L. A. dos A.; Silva, L. de A.; Oliveira, V. K. N.; Fátima, R. T. de; Nobre, R. G.; Nóbrega, J. S.; Azevedo, C. A. V. de; Silva, S. S. da; Gomes, J. P. Hydroponic cultivation of laranja cherry tomatoes under salt stress and foliar application of hydrogen peroxide. Agriculture, v.13, e1688, 2023. https://doi.org/10.3390/agriculture13091688

Khan, T. A.; Yusuf, M.; Fariduddin, Q. Hydrogen peroxide in regulation of plant metabolism: signalling and its effect under abiotic stress. Photosynthetica, v.56, p.1237-1248, 2018. https://doi.org/10.1007/s11099-018-0830-8

Lacerda, F. H. D.; Pereira, F. H. F.; Silva, F. A. da; Queiroga, F. M. de; Brito, M. E. B.; Medeiros, J. E.; Dias, M. dos S. Physiology and growth of maize under salinity of water and application of hydrogen peroxide. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.771-779, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n11p771-779

Monteiro, S. S.; Monteiro, S. S.; Silva, E. A. da.; Martins, L. P. Maturidade fisiológica de tomate cereja. Revista Brasileira de Agrotecnologia, v.8, p.5-9, 2018.

Nóbrega, J. S.; Figueiredo, F. R. de A.; Silva, T. I. da; Fátima, R. T. de; Ferreira, J. T. A.; Ribeiro, J. E. da S. R.; Bruno, R. de L. A. Ecophysiology of *Mesosphaerum suaveolens* (L.) Kuntze (Lamiaceae) under saline stress and salicylic acid. Ciência Rural, v.52, p.1-9, 2022. https://doi.org/10.1590/0103-8478cr20210389

Nóbrega, J. S.; Silva, T. I. da; Lopes, A. S.; Costa, R. N. M.; Ribeiro, J. E. da S.; Silva, E. C. da; Bezerra, A. C.; Silva, A. V. da; Dias, T. J. Foliar nitrogen fertilization attenuating harmful effects of salt stress on purple basil. Revista Brasileira de Engenharia Agrícola e Ambiental, v.27, p.472-479, 2023. https://doi.org/10.1590/1807-1929/agriambi.v27n6p472-479

Ramos, J. G.; Lima, V. L. A. de; Lima, G. S. de; Paiva, F. J. da S.; Pereira, M. de O.; Nunes, K. G. Hydrogen peroxide as salt stress attenuator in sour passion fruit. Revista Caatinga, v.35, p.412-422, 2022a. http://dx.doi.org/10.1590/1983-21252022v35n217rc

Ramos, J. G.; Lima, V. L. A. de; Lima, G. S. de; Pereira, M. de O.; Silva, A. A. R. da; Nunes, K. G. Growth and quality of passion fruit seedlings under salt stress and foliar application of H_2O_2. Comunicata Scientiae, v.13, p.1-11, 2022b. https://doi.org/10.14295/cs.v13.3393

Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington: U.S, Department of Agriculture. 1954. 160p. USDA Handbook 60

Roque, I. A.; Soares, L. A. dos A.; Lima, G. S. de; Lopes, I. A. P.; Silva, L. de A.; Fernandes, P. D. Biomass, gas exchange and production of cherry tomato cultivated under saline water and nitrogen fertilization. Revista Caatinga, v.35, p.686-696, 2022. http://dx.doi.org/10.1590/1983-21252022v35n320rc

Santos, A. S.; Almeida, J. F.; Silva, M. S.; Nóbrega, J. S.; Queiroga, T. B. de; Pereira, J. A. R.; Linné, J. A.; Gomes, F. A. L. The influence of H_2O_2 application methods on melon plants submitted to saline stress. Journal of Agricultural Science, v.11, p.245-252, 2019. https://doi.org/10.5539/jas.v11n11p245

Silva, A. A. R. da; Capitulino, J. D.; Lima, G. S. de; Azevedo, C. A. V. de; Arruda, T. F. de L.; Souza, A. R. de; Gheyi, H. R.; Soares, L. A. dos A. Hydrogen peroxide in attenuation of salt stress effects on physiological indicators and growth of soursop. Brazilian Journal of Botany, v.84, p.1-8, 2024. https://doi.org/10.1590/1519-6984.261211

Silva, A. A. R. da; Veloso, L. L. de S.; Lima, G. S. de; Azevedo, C. A. V. de; Gheyi, H. R.; Fernandes, P. D. Hydrogen peroxide in the acclimation of yellow passion fruit seedlings to salt stress. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.116-123, 2021. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n1p3-9

Silva, A. A. R. da; Veloso, L. L. de S.; Lima, G. S. de; Soares, L. A. dos A.; Chaves, L. H. C.; Silva, F. A. da; Dias, M. dos S.; Fernandes, P. D. Induction of salt stress tolerance in cherry tomatoes under different salicylic acid application methods. Semina: Ciências Agrárias, v.43, p.1145-1166, 2022. https://doi.org/10.5433/1679-0359.2022v43n3p1145

Teixeira, P. C.; Donagemma, G. K.; Fontana, A.; Teixeira, W. G. Manual de métodos de análise de solo. 3. ed. Brasília: Embrapa, 2017, 573p.

Trani, P. E.; Kariya, E. A.; Hanai, S. M.; Anbo, R. H.; Basseto Júnior, O. B.; Purquerio, L. F. V.; Trani, A L. Calagem e adubação do tomate de mesa. Campinas: Instituto Agronômico, 2015, 35p. Boletim Técnico IAC

Veloso, L. L. A. de S.; Silva, A. A. R. da; Lima, G. S. de; Azevedo, C. A. V. de; Gheyi, H. R.; Moreira, R. C. L. Growth and gas exchange of soursop under salt stress and hydrogen peroxide application. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.119-125, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n2p119-125