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Foliar Ascorbic Acid Enhances Postharvest Quality of Cherry Tomatoes in Saline Hydroponic Substrate System

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Abstract

Ascorbic acid is a non-enzymatic antioxidant compound essential for plant defense under salt stress conditions. It can induce salt stress tolerance and enable the use of saline water in hydroponic cultivation with substrates. This study evaluated the effect of foliar application of ascorbic acid on the yield and postharvest quality of 'Laranja' cherry tomatoes grown in saline nutrient solutions under a substrate-based hydroponic system. The experiment was conducted in a greenhouse in Campina Grande, Paraíba, Brazil, in a randomized block design in a 5 × 5 factorial arrangement, corresponding to five levels of electrical conductivity of the saline nutrient solution—SNS (2.1—Control, 2.8, 3.5, 4.2, and 4.9 dS m^{-1}) and five concentrations of ascorbic acid—AA (0, 150, 300, 450, and 600 mg L^{-1}), with four replications. Salinity above 2.1 dS m^{-1} reduced yield components and phenolic compound content. However, the saline nutrient solution of 4.9 dS m^{-1} combined with 600 mg L^{-1} foliar application of AA increased fruit firmness, soluble solids, and titratable acidity. Additionally, SNS of 4.9 dS m^{-1} enhanced the levels of vitamin C, flavonoids, and anthocyanins. While AA improved postharvest quality of cherry tomatoes, it did not increase production under salt stress. Foliar application is thus a promising approach for enhancing fruit quality of cherry tomatoes grown in hydroponic systems using saline water, supporting sustainable production in semiarid regions.

Keywords: *Solanum lycopersicum* var. cerasiforme; hydroponics; salt stress; ascorbic acid; antioxidant treatment

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1. Introduction

The 'Laranja' cherry tomato (*Solanum lycopersicum* var. cerasiforme) is a variety with increasing production among tomato types. Although it is smaller than traditional tomatoes, it is a versatile ingredient in modern cuisine, characterized by a high antioxidant content and a sweeter flavor, making it more palatable [1]. As a result, consumer demand is high, and it commands favorable prices in the market [2]. Brazil's national tomato production totaled 4,166,017 tons, with the Northeast region accounting for 16.9%, equivalent to 704,424 tons [3].

The semi-arid region of Brazil's Northeast is characterized by limited water resources, both in terms of quality and quantity, with irregular rainfall and high evapotranspiration rates [4]. Therefore, irrigation is essential for agricultural production. In many cases, however, farmers rely on water sources with high concentrations of dissolved salts, which can negatively affect crop performance [5]. Excess dissolved salts in irrigation water can lead to osmotic, ionic, and oxidative stress, directly impacting crop yield and the postharvest quality of fruits [6–8].

Given this scenario, hydroponic cultivation offers a valuable alternative for using saline water, as it can mitigate the effects of salt stress in plants due to the absence of matric potential [9]. In addition, it consumes less water than conventional systems by employing a nutrient solution in combination with an inert solid substrate, which retains moisture for longer periods in the containers, thereby supporting efficient plant growth and development [10].

Specifically, substrate-based hydroponics is often preferred over other soilless methods for its resource efficiency. By providing physical root support and enabling longer irrigation intervals, it reduces the need for the complex infrastructure, energy, and labor demands typically associated with other techniques. Hutchinson et al. [11] reported that substrate-grown strawberries achieved higher yields and greater resource-use efficiency compared to those grown in nutrient film technique (NFT), vertical, or aeroponic systems.

Several studies have addressed the effects of salt stress on yield and postharvest quality in various crops, including cherry tomatoes. Nóbrega et al. (2024) [4], working with cherry tomato plants irrigated with water of different electrical conductivity—ECw (0.3, 1.0, 1.7, 2.4, and 3.1 dS m^{-1}), observed that ECw levels above 1.41 dS m^{-1} reduced yield. Similarly, Roque et al. [2] reported that ECw levels exceeding 0.3 dS m^{-1} decreased yield components in tomato plants under increasing salinity (0.3, 1.3, 2.3, 3.3, and 4.3 dS m^{-1}).

Martínez et al. [12] also observed reductions in fruit weight in tomato due to salinity; however, these losses were accompanied by increases in total soluble solids, lycopene content, and titratable acidity. It is worth noting that such physicochemical attributes are key indicators of product quality and consumer acceptability, as they strongly influence both the flavor and shelf life of the tomatoes.

The induction of salt stress tolerance in crops through the foliar application of ascorbic acid (AA) has been widely documented in the literature [13–15], offering potential for the use of saline water in substrate-based hydroponic systems. Ascorbic acid is a key non-enzymatic antioxidant in plants, capable of directly scavenging reactive oxygen species (ROS) such as singlet oxygen ($^1O_2$), molecular oxygen (O_2), and hydroxyl radicals (•OH). It also plays a role in regenerating vitamin E and serves as a cofactor for ascorbate peroxidase (APX), playing a central role in the plant's antioxidant defense mechanisms [16].

In addition, AA can enhance crop yield under both optimal and stress conditions, thereby increasing economic returns [17]. In hydroponic systems utilizing saline water, such benefits have been demonstrated by Naz et al. [18] in lettuce (*Lactuca sativa*). In tomatoes, however, most studies have been limited to the seedling stage. For instance,

Chen et al. [15] reported that foliar AA application improved chlorophyll biosynthesis, enhanced the uptake of essential elements, and optimized stomatal function.

In summary, considering that salt stress is a major limiting factor for cherry tomato production, this study was based on the hypothesis that foliar application of AA can induce salt stress tolerance mechanisms through its role in antioxidant metabolism, thereby improving yield and postharvest fruit quality of the 'Laranja' cherry tomato. This research fills a notable gap in the literature by evaluating the effects of AA specifically on the 'Laranja' cherry tomato cultivar grown in a substrate-based hydroponic system, a cultivation method less studied for this crop compared with the Nutrient Film Technique (NFT).

In this context, the objective of the present study was to evaluate the beneficial effects of foliar application of ascorbic acid on yield and its components and postharvest quality of 'Laranja' cherry tomato grown in saline nutrient solutions under a hydroponic system using a substrate.

2. Materials and Methods

2.1. Experimental Site Location

The experiment was conducted in the municipality of Campina Grande, Paraíba, Brazil, in a greenhouse belonging to the Academic Unit of Agricultural Engineering (UAEA) at the Federal University of Campina Grande (UFCG). The site is located at the geographic coordinates 7°15′18″ S latitude and 35°52′28″ W longitude, with an average altitude of 550 m. The regional climate is classified as As—tropical with a dry summer—according to the Köppen's climate classification adapted for the state of Paraíba [19].

The greenhouse has an arched structure covered with low-density transparent polyethylene film, 150 µm thick, and its sides are lined with 80% shade netting. From 12 April to 29 July 2024, daily records of maximum and minimum temperatures and average relative air humidity were taken using a digital thermo-hygrometer installed inside the greenhouse (Figure 1).

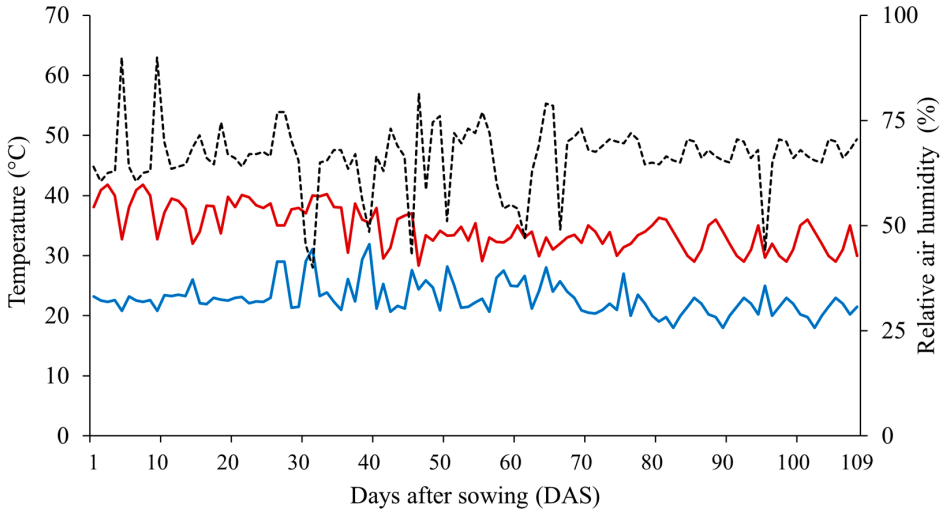

Figure 1. Maximum (—) and minimum (—) temperatures, and average relative air humidity (---) inside the greenhouse between 12 April and 29 July 2024.

2.2. Treatments and Experimental Design

This study evaluated five levels of electrical conductivity of the saline nutrient solution (SNS)—2.1 (control), 2.8, 3.5, 4.2, and 4.9 dS m^{-1}—and five concentrations of ascorbic acid (AA): 0, 150, 300, 400, and 600 mg L^{-1}. The treatments were arranged in a 5 × 5 factorial scheme, in a randomized block design with four replications, and each experimental unit consisted of a single plant. The SNS levels were adapted from the study conducted by

Guedes et al. [20] with cherry tomatoes under a hydroponic system using the nutrient film technique (NFT). The AA concentrations were based on the work of Gaafar et al. [21].

2.3. Studied Cultivar

The cherry tomato cultivar 'Laranja' from Topseed Garden® was selected for this study due to its resistance to Fusarium wilt and nematodes [22]. This cultivar has a determinate growth habit, a crop cycle of approximately 90 days, and produces fruits with a length and diameter ranging between 20 and 25 mm.

2.4. Experimental Setup and Management

A hydroponic system with a solid substrate was employed for plant cultivation. Plants were grown in plastic pots (25 × 27 × 19 cm: height, top diameter, and bottom diameter, respectively) with a capacity of 10 L. The base of each pot was perforated to install a 10 mm drainage tube, secured with a 15 cm piece of wire. A 2 L plastic bottle was connected to collect and recirculate the drained nutrient solution, enabling monitoring of electrical conductivity (EC) and pH, as well as estimation of plant water consumption.

Inside each pot, a layer of nonwoven geotextile fabric (Bidim) was placed over the drainage outlet. The pots were then filled with 13 kg of washed sand (Grade 0). Plant spacing was 0.6 m between pots and 1.0 m between rows. Data on nutrient solution consumption under the different salinity levels are shown in Table 1.

Table 1. Water consumption of 'Laranja' cherry tomato plants under different electrical conductivity levels of the nutrient solution.

Saline nutrient solution (dS m^{-1})	2.1	2.8	3.5	4.2	4.9
Water consumption (L per plant)	134.60	128.70	71.60	64.81	61.86

Sowing was carried out directly in the pots, placing three seeds equidistantly, at 5 cm spacing and an average depth of 2 cm. Thinning was carried out at 33 days after sowing (DAS), when the seedlings had developed one pair of true leaves, retaining only the most vigorous plant per pot. Plant training was done using vertical staking to support the main stem (Figure 2).

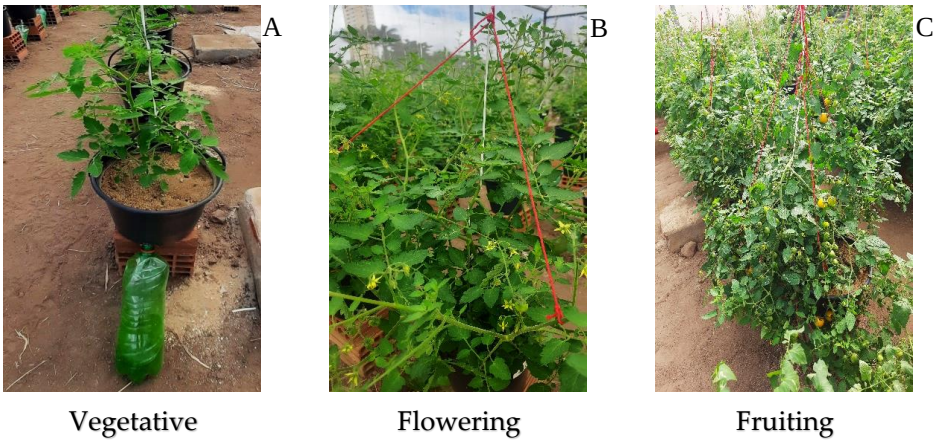

Figure 2. Cultivation of 'Laranja' cherry tomato in a substrate-based hydroponic system during the vegetative (**A**), flowering (**B**), and fruiting (**C**) stages.

2.4.1. Preparation of Nutrient Solutions

Before applying the nutrient solutions, the substrate was irrigated with low-electrical-conductivity water (ECw 0.4 dS m^{-1}) from seedling emergence until 13 DAS. After this

period, the nutrient solution was applied following the formulation of Hoagland and Arnon [23], containing the following concentrations (in mg L^{-1}) of essential nutrients: N (210), P (31), K (234), Ca (200), Mg (48), S (64), B (0.5), Mn (0.5), Zn (0.05), Cu (0.02), Mo (0.01), and Fe (5). Macronutrients were supplied using monobasic potassium phosphate (KH_2PO_4), potassium nitrate (KNO_3), calcium nitrate ($Ca(NO_3)_2 \cdot 4H_2O$), and magnesium sulfate ($MgSO_4 \cdot 7H_2O$). Micronutrients were provided through boric acid (H_3BO_3), manganese sulfate ($MnSO_4 \cdot H_2O$), zinc sulfate ($ZnSO_4 \cdot 7H_2O$), copper sulfate ($CuSO_4 \cdot 5H_2O$), ammonium molybdate ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$), ferrous sulfate ($FeSO_4$), and EDTA.

The solution was prepared by diluting a stock solution (containing both macro- and micronutrients) in local municipal supply water with an ECw of 0.4 dS m^{-1}, resulting in a final electrical conductivity of 2.1 dS m^{-1}. During seedling development, a 50% diluted nutrient solution was applied starting at 14 DAS. From 23 DAS onward, the full-strength (100%) nutrient solution was employed. The pH of the solution was maintained between 5.5 and 6.5 by adding either 0.1 M potassium hydroxide (KOH) or hydrochloric acid (HCl), as required.

2.4.2. Preparation and Management of Saline Nutrient Solutions

The saline nutrient solutions were formulated by adding sodium chloride (NaCl), calcium chloride ($CaCl_2 \cdot 2H_2O$), and magnesium chloride ($MgCl_2 \cdot 6H_2O$) in an equivalent ionic ratio of 7:2:1 for Na, Ca, and Mg, respectively. Different levels of electrical conductivity of the SNS were obtained based on the relationship between SNS and salt concentration [24], as shown in Equation (1).

$$C\left(\text{mmol}_c\ L^{-1}\right) = 10 \times \text{SNS} \quad (1)$$

in which:

C = concentration of salts to be applied ($\text{mmol}_c\ L^{-1}$);
SNS = electrical conductivity of the nutrient solution, subtracting the control SNS (2.1 dS m^{-1}).

Recirculation of the nutrient solution began 72 h after the application of AA (at 31 DAS) and was carried out manually twice a day: in the morning (9:00 a.m.) and afternoon (3:00 p.m.), a schedule based on previous experiments. Before each recirculation event, the drained nutrient solution was collected and its volume recorded, which was then used to estimate plant water consumption. When the drained solution was depleted, a fresh nutrient solution was applied. The saline nutrient solutions, once prepared, were stored in 200 L containers. It is noteworthy that the solutions were replaced frequently, whenever variations in the electrical conductivity of the control solution (2.1 dS m^{-1}) were observed.

2.4.3. Preparation and Application of Ascorbic Acid

The ascorbic acid (AA) solutions were prepared by dissolving the appropriate amount (according to the treatment) in distilled water. The solution was prepared on the day of each application due to the compound's high volatility. The first application was made 72 h prior to the introduction of the saline nutrient solutions (28 DAS). Subsequent applications were performed every 10 days until the onset of the fruiting stage, totaling three applications. Foliar applications were carried out using a handheld sprayer, thoroughly wetting both sides of the leaves to ensure full coverage.

A surfactant (Tween 20 at 0.025% concentration) was added to the spray solution to reduce surface tension and improve its penetration into the leaf tissue. During AA applications, plants were isolated with plastic curtains to prevent spray drift to neighboring treatments. An average volume of 108 mL of solution was applied per plant over the course of the experiment.

2.4.4. Phytosanitary Control

Phytosanitary control was conducted throughout the experiment using chemical pesticides. Insecticides were applied in rotation to prevent resistance, using active ingredients such as deltamethrin, thiamethoxam, and imidacloprid, targeting whitefly (*Bemisia tabaci*, biotype B) and leafminer larvae (*Liriomyza* spp.). As a preventive measure, a fungicide—thiophanate-methyl—was also applied.

2.5. Evaluated Traits

2.5.1. Yield

Fruits were harvested between 72 and 108 days after sowing (DAS), when they reached the characteristic orange color of mature 'Laranja' cherry tomatoes. Yield-related variables included: Total fruit yield per plant, determined using a digital scale and expressed in grams per plant (g plant^{-1}); Average fruit weight, calculated by dividing the total yield by the number of fruits, expressed in grams (g); Number of fruits and fruit clusters per plant, recorded by direct counting.

2.5.2. Physical Characterization of Fruits

Fruit physical characteristics included measurements of polar and equatorial diameters and firmness: Diameters were measured with a digital caliper on 20 fruits per treatment and expressed in millimeters (mm). Fruit firmness was determined on 5 fruits per treatment using a penetrometer (Multcort; range: 0.4–30 kgf cm^{-2}, which was calibrated and zeroed before each measurement.

2.5.3. Chemical Characterization of Fruits

Soluble solids (SS) were determined from a 100 g sample of homogenized fruit pulp. A few drops of juice were extracted and measured using a handheld refractometer (ATC® model) to obtain the °Brix value.

Titratable acidity (TA) was quantified following Equation (2), as described by IAL [25]. A 3 g sample was weighed into a 125 mL Erlenmeyer flask, to which 50 mL of distilled water and two drops of phenolphthalein indicator were added. The titration was performed using 0.1 N sodium hydroxide (NaOH) as the titrant.

$$\text{Titratable acidity}\left(\frac{\text{g}}{100\ \text{g}}\right) = \frac{(\text{V} \times \text{f} \times \text{N} \times 64.04)}{(10 \times \text{Pa})} \quad (2)$$

in which:

V = volume of 0.1 M NaOH solution used in the titration (mL);
F = correction factor of the titrant solution;
N = normality of the NaOH solution (0.1);
64.04 = conversion factor for citric acid;
Pa = mass of the sample used (g).

The maturity index was calculated as the ratio of total soluble solids (°Brix) to titratable acidity. The pH was determined by weighing 3 g of the sample into a 100 mL beaker, followed by the addition of 50 mL of distilled water. The mixture was homogenized using a glass rod and left to rest for 15 min. The pH reading was then taken by immersing the electrode in the diluted sample and recording the value after stabilization of the pH meter [25], which was previously calibrated using standard buffer solutions (pH 4.0 and 7.0).

The vitamin C content was determined using 1 g of the sample placed in a 250 mL Erlenmeyer flask, followed by the addition of 50 mL of 0.5% oxalic acid solution. The mixture was homogenized using a Vortex® stirrer (Warmnest, Salvador, Brazil). Titration

was performed using a 2,6-dichlorophenolindophenol (DCPIP) solution until a persistent pink coloration was observed. Vitamin C content was quantified using Equation (3) [26,27].

$$\text{Vit C}\left(\frac{\text{mg}}{100\ \text{g}}\right) = \frac{(\text{V} \times \text{F} \times 100)}{\text{Pa}} \quad (3)$$

in which:

V = volume of DCPIP solution used in the titration (mL);
F = correction factor of the DCPIP solution;
Pa = sample mass (g).

Reducing sugars were determined using the dinitrosalicylic acid (DNS) method. Initially, 1 g of sample was weighed and macerated with distilled water using a mortar and pestle. The homogenate was then transferred to a 50 mL volumetric flask and brought to volume with distilled water, followed by a resting period of 30 min. After this, the extract was filtered using filter paper. In screw-cap glass tubes, an aliquot of 500 µL of the extract (based on preliminary tests) was mixed with 500 µL of DNS reagent. The tubes were shaken and placed in a water bath at 100 °C for 15 min. After heating, tubes were cooled, and 4 mL of distilled water was added, completing the final volume to 5 mL. Absorbance readings were taken using a UV spectrophotometer (SP 2000 UV) (Biospectro, Shangai, China) at a wavelength of 540 nm [28].

Flavonoid and anthocyanin contents were determined following the method described by Francis [29]. A 1 g sample was mixed with 10 mL of an extraction solution composed of 95% ethanol and 1.5 N HCl in an 85:15 ratio. The mixture was homogenized and macerated for 1 min, then transferred to aluminum foil–wrapped tubes and left to rest for 24 h. Absorbance of the extract was then measured with a spectrophotometer at 374 nm (flavonoids) and 535 nm (anthocyanins).

Total phenolic content was determined using extracts prepared by macerating 1 g of sample with distilled water in a mortar and pestle. The homogenate was transferred to a 50 mL volumetric flask, brought to volume with distilled water, then left to stand for 30 min. The extract was filtered through filter paper. For each reaction tube, 900 µL of the extract, 1225 µL of distilled water, and 125 µL of Folin–Ciocalteu® reagent were added.

The mixture was agitated and allowed to rest for 5 min. Subsequently, 250 µL of 20% sodium carbonate solution was added, followed by agitation. The tubes were incubated in a water bath (SL 150/10) at 40 °C for 30 min. After cooling, absorbance was measured at 765 nm using a UV spectrophotometer (SP 2000 UV) [30].

2.6. Statistical Analysis

The data obtained were first subjected to a normality test (Shapiro–Wilk), followed by analysis of variance (ANOVA) using the F-test at a 5% probability level ($p \leq 0.05$). For the saline nutrient solution levels and ascorbic acid concentrations, polynomial regression analysis was performed using SISVAR—ESAL, version 5.7 [31]. In cases where a significant interaction between factors (SNS × AA) was observed, response surface curves were generated using SigmaPlot® v.12.5 software.

3. Results

The electrical conductivity levels of the nutrient solution significantly influenced total yield (TY), average fruit weight (AFW), number of fruit clusters (NFC), number of fruits (NF), polar diameter (PD), and equatorial diameter (ED) of 'Laranja' cherry tomato fruits during the period from 72 to 108 days after sowing (DAS) (Table 2). However, no significant effects were observed for the interaction between factors (SNS × AA) or for the isolated effect of ascorbic acid concentrations on the evaluated traits.

Table 2. Summary of the analysis of variance for total yield (TY), average fruit weight (AFW), number of fruit clusters (NFC), number of fruits (NF), polar diameter (PD), and equatorial diameter (ED) of 'Laranja' cherry tomato fruits grown under saline nutrient solutions electrical conductivity levels (SNS) and foliar application of ascorbic acid (AA), during the period from 72 to 108 days after sowing (DAS).

Source of Variation	DF	Mean Squares					
		TY	AFW	NFC	NF	PD	ED
Saline nutrient solution (SNS)	4	5,426,576.42 **	5.3012 **	3520.88 **	154,577.94 **	52.9045 **	95.862 **
Linear regression	1	21,155,649.94 **	19.6119 **	14,044.88 **	609,518.40 **	186.747 **	351.098 **
Quadratic regression	1	332,621.48 *	0.9782 *	8.93 ^{ns}	150.09 ^{ns}	16.835 **	27.462 **
Ascorbic acid (AA)	4	102,896.82 ^{ns}	0.0420 ^{ns}	150.21 ^{ns}	4328.31 ^{ns}	0.3280 ^{ns}	1.083 ^{ns}
Linear regression	1	4804.09 ^{ns}	0.1072 ^{ns}	136.12 ^{ns}	6555.12 ^{ns}	0.8115 ^{ns}	1.654 ^{ns}
Quadratic regression	1	167,600.58 ^{ns}	0.0212 ^{ns}	225.003 ^{ns}	130,074.02 ^{ns}	0.2286 ^{ns}	0.0009 ^{ns}
Interaction (SNS × AA)	16	59,568.68 ^{ns}	0.2792 ^{ns}	204.86 ^{ns}	2668.73 ^{ns}	0.4924 ^{ns}	1.672 ^{ns}
Blocks	3	112,677.83 ^{ns}	0.9119 ^{ns}	1989.77 ^{ns}	1563.55 ^{ns}	1.9993 ^{ns}	2.473 ^{ns}
Residue	72	83,852.47	0.2110	206.42	3192.17	0.5658	1.3072
CV (%)		23.44	11.33	33.37	19.24	3.40	5.30

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

Total yield (TY) and average fruit weight (AFW) of cherry tomatoes decreased with increasing electrical conductivity levels of the nutrient solution (Figure 3A,B). The highest estimated values—1954.9 g per plant for TY and 4.80 g per fruit for AFW—were obtained under the lowest SNS level (2.1 dS m^{-1}). In comparison, plants grown under the highest SNS level (4.9 dS m^{-1}) showed reductions of 66.55% (1300.94 g per plant) in TY and 26.11% (1.25 g) in AFW, relative to those under the lowest EC level.

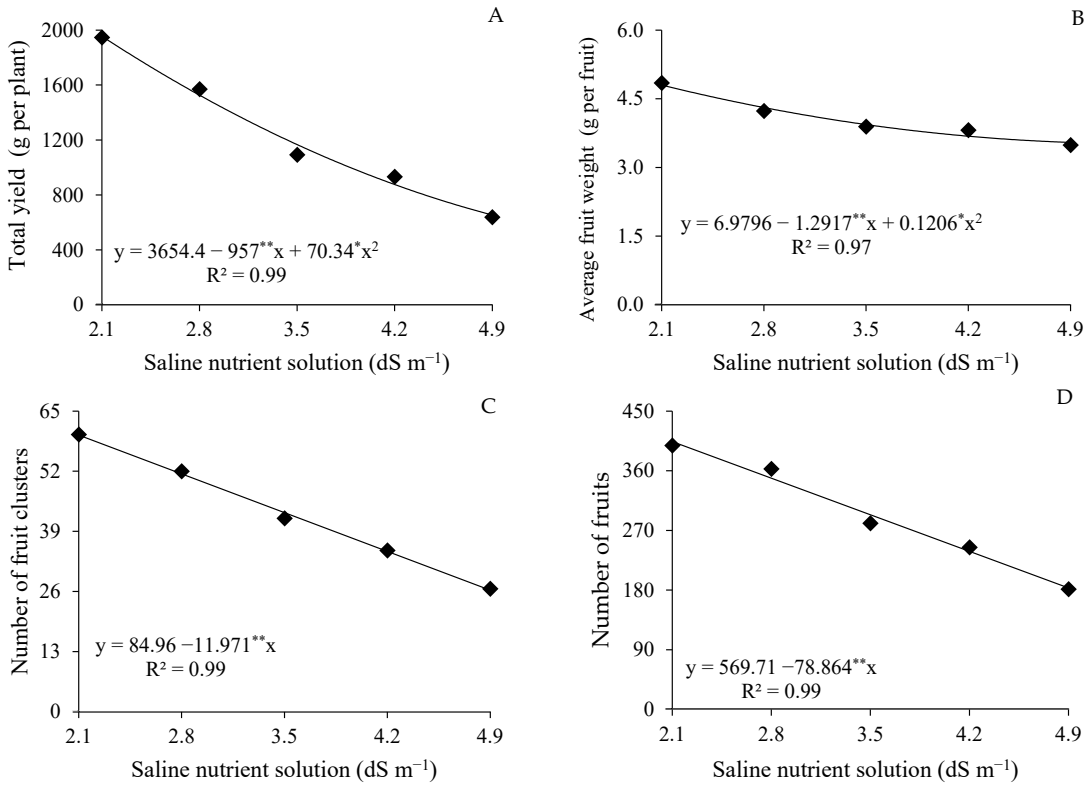

Figure 3. Total yield (**A**), average fruit weight (**B**), number of fruit clusters—NFC (**C**), and number of fruits—NF (**D**) of 'Laranja' cherry tomato plants as a function of saline nutrient solution electrical conductivity levels during the period from 72 to 108 days after sowing. planting. ** significant at $p \leq 0.01$ by F test.

The number of fruit clusters per plant (Figure 3C) showed a linear decrease, with a 14.09% reduction for each unit increase in SNS. Comparing plants grown under SNS of 2.1 dS m^{-1} to those under 4.9 dS m^{-1}, there was a 56.03% decline (equivalent to 34 clusters).

Similarly, the number of fruits per plant also decreased linearly with increasing SNS levels (Figure 3D). Plants exposed to an SNS of 4.9 dS m^{-1} had 54.65% fewer fruits (221 fruits per plant) compared to those grown under 2.1 dS m^{-1}.

The polar diameter (PD) (Figure 4A) and equatorial diameter (ED) (Figure 4B) of 'Laranja' cherry tomato fruits also decreased linearly as SNS levels increased, with reductions of 5.12% and 6.71%, respectively, for each unit increase in SNS. The largest diameters—24.06 mm for PD and 24.23 mm for ED—were recorded in plants grown with the nutrient solution at 2.1 dS m^{-1}.

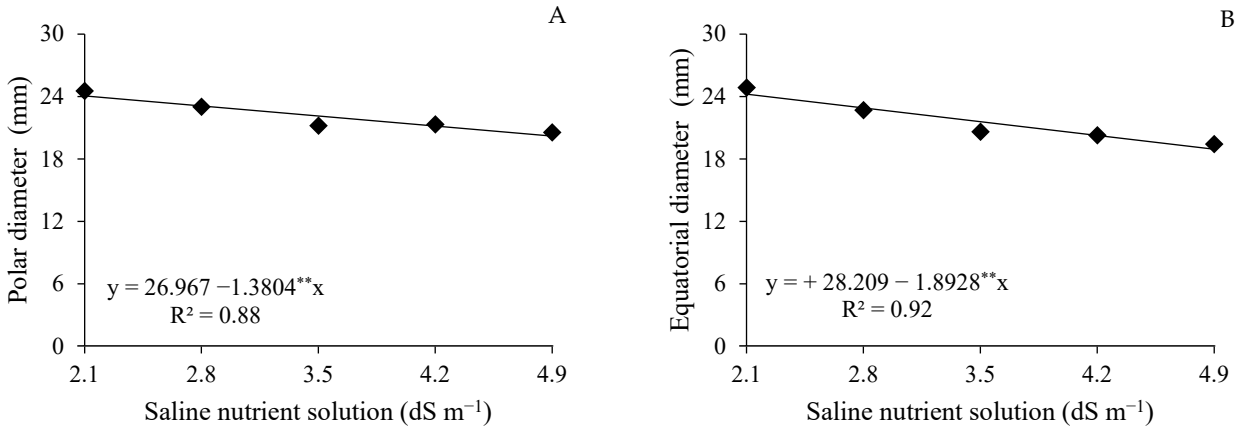

Figure 4. Polar diameter (**A**) and equatorial diameter (**B**) of 'Laranja' cherry tomato fruits as a function of saline nutrient solution electrical conductivity levels during the period from 72 to 108 days after sowing. ** significant at $p \leq 0.01$ by F test.

A significant interaction between the factors (SNS × AA) was observed for fruit firmness (FIRM), soluble solids (SS), titratable acidity (TA), and vitamin C (Vit C) content of 'Laranja' cherry tomato fruits at 108 days after sowing (DAS) (Table 3). However, no significant effects were found for the maturation index or pH for any of the tested sources of variation.

Table 3. Summary of the analysis of variance for firmness (FIRM), soluble solids (SS), titratable acidity (TA), maturation index (MI), pH, and vitamin C (Vit C) content of 'Laranja' cherry tomato fruits grown under saline nutrient solution electrical conductivity levels (SNS) and foliar application of ascorbic acid (AA), at 108 days after sowing (DAS).

Source of Variation	DF	Mean Squares					
		FIRM	SS	TA	MI	pH	Vit C
Saline nutrient solution (SNS)	4	2.3801 **	18.8 **	0.001784 **	0.0881 ^{ns}	0.046 ^{ns}	1.6172 **
Linear regression	1	8.5615 **	58.32 ^{ns}	0.003135 **	0.1479 ^{ns}	0.002 ^{ns}	5.6558 **
Quadratic regression	1	0.4512 ^{ns}	16.51 ^{ns}	0.002390 **	0.0133 ^{ns}	0.0232 ^{ns}	0.6045 **
Ascorbic acid (AA)	4	0.1835 ^{ns}	0.4 **	0.000592 **	0.0657 ^{ns}	0.01 ^{ns}	0.0762 ^{ns}
Linear regression	1	0.3049 ^{ns}	0.32 ^{ns}	0.001546 **	0.1052 ^{ns}	0.001 ^{ns}	0.0081 ^{ns}
Quadratic regression	1	0.0004 ^{ns}	0.9143 ^{ns}	0.000004 ^{ns}	0.0082 ^{ns}	0.0053 ^{ns}	0.2470 *
Interaction (SNS × AA)	16	1.4250 **	1.2 **	0.000259 **	0.0757 ^{ns}	0.004 ^{ns}	0.4843 **
Blocks	3	0.2362 ^{ns}	1 ^{ns}	0.00007 ^{ns}	0.0036 ^{ns}	0.0005 ^{ns}	0.1644 ^{ns}
Residue	72	0.1592	1	0.0687	0.0021	0.0001	0.0521
CV (%)		11.04	0	3.29	4.44	0.31	8.68

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

For the firmness (FIRM, $p \leq 0.05$) of cherry tomato fruits (Figure 5), the plants grown under a salinity level of 4.9 dS m^{-1} and sprayed with 600 mg L^{-1} of ascorbic acid (AA) showed the highest value (4.15 kgf cm^{-2}), representing an increase of 29.57% compared to those irrigated with an SNS of 2.1 dS m^{-1} and without AA spraying (0 mg L^{-1}), which recorded a value of 3.20 kgf cm^{-2}. Therefore, foliar application of 600 mg L^{-1} in combination with a salinity of 4.9 dS m^{-1} may promote greater fruit firmness.

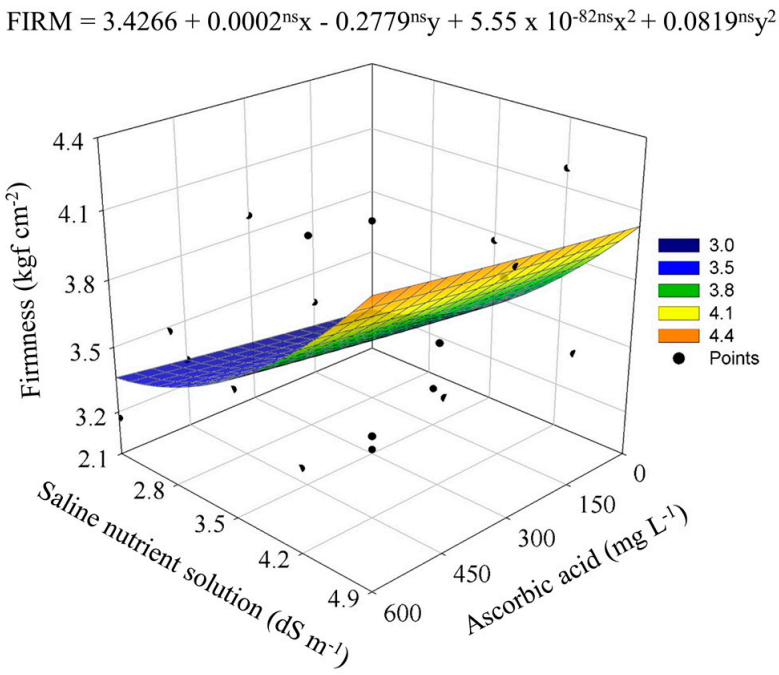

Figure 5. Firmness (FIRM) of 'Laranja' cherry tomato fruits as a function of the interaction between electrical conductivity levels of the saline nutrient solution and ascorbic acid (AA) concentrations, measured at 108 days after sowing. x and y—Ascorbic acid concentration and electrical conductivity of the saline nutrient solution (SNS), respectively. ^{ns}, not significant by F test

Soluble solids (SS, $p \leq 0.01$) and titratable acidity (TA, $p \leq 0.01$) increased with higher levels of SNS and AA concentrations (Figure 6A,B). The foliar application of 600 mg L^{-1} combined with irrigation at a SNS of 4.9 dS m^{-1} resulted in the highest values for SS (9 °Brix) and TA (8.54 g 100 g^{-1}) in the fruits, representing increases of 6.66% and 10.53%, respectively, compared to those irrigated with the same salinity level (SNS 4.9 dS m^{-1}) but without AA application (0 mg L^{-1}).

Vitamin C (Vit C, $p \leq 0.05$) content in the cherry tomato fruits increased with rising SNS levels and decreased with increasing AA concentrations (Figure 6C). The highest estimated vitamin C content (3.10 mg 100 g^{-1}) was found in fruits from plants grown under SNS of 4.9 dS m^{-1} with no AA application (0 mg L^{-1}), while the lowest value (2.01 mg 100g^{-1}) was observed in fruits from plants grown under SNS of 2.1 dS m^{-1} and sprayed with 600 mg L^{-1} of AA.

A significant interaction effect between SNS and AA was found for the levels of flavonoids (FLV) and anthocyanins (ANT) in 'Laranja' cherry tomato fruits (Table 4). The SNS levels also influenced the content of phenolic compounds (PC) in the fruits at 108 DAS. However, there was no significant effect of the tested factors on the content of reducing sugars (RS).

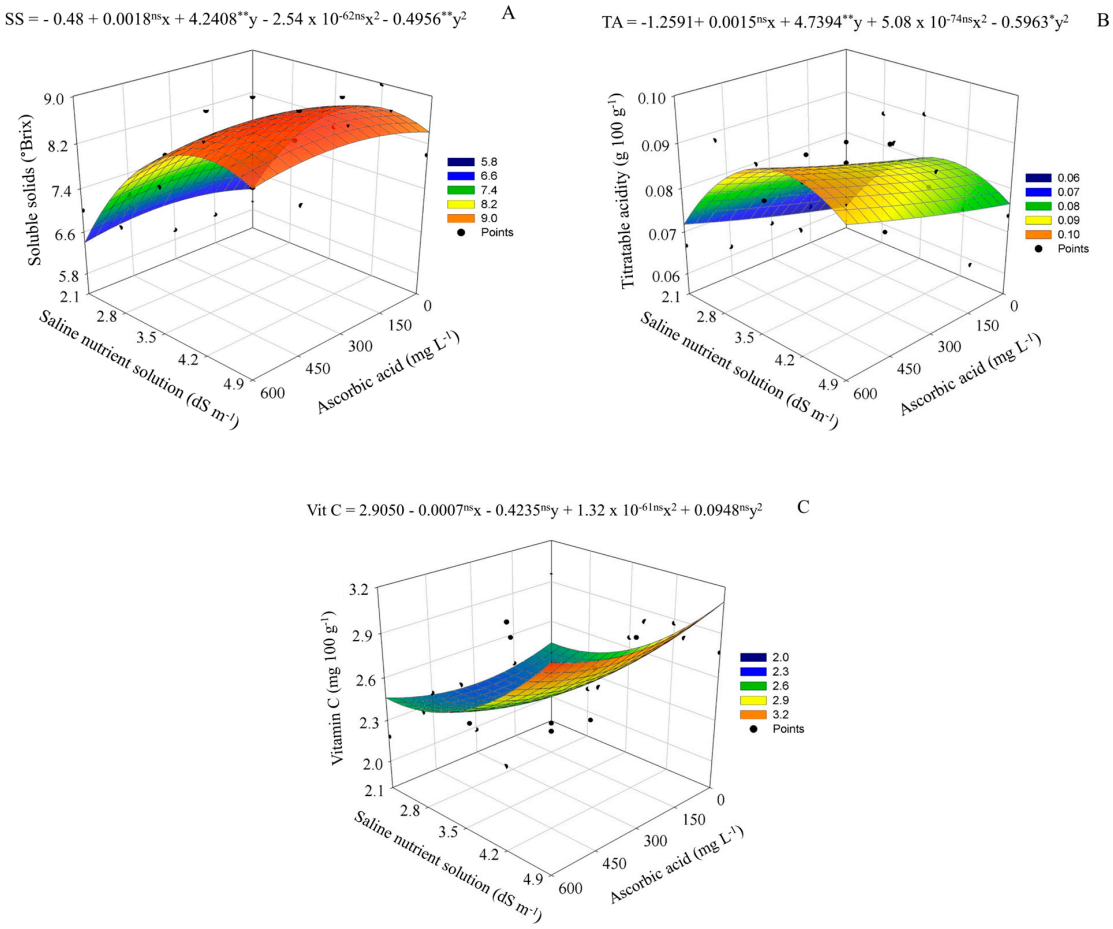

Figure 6. Soluble solids—SS (**A**), titratable acidity—TA (**B**), and vitamin C—Vit C (**C**) in 'Laranja' cherry tomato fruits as a function of the interaction between saline nutrient solution electrical conductivity levels and ascorbic acid (AA) concentrations, measured at 108 days after sowing. x and y—Ascorbic acid concentration and electrical conductivity of the saline nutrient solution (SNS), respectively. ^{ns}, * and ** not significant ($p > 0.05$) and significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively

Table 4. Summary of the analysis of variance for reducing sugars (RS), flavonoids (FLV), anthocyanins (ANT), and phenolic compounds (PC) in 'Laranja' cherry tomato fruits grown under saline nutrient solutions electrical conductivity levels (SNS) and foliar application of ascorbic acid (AA), at 108 days after sowing (DAS).

Source of Variation	DF	Mean Squares			
		RS	FLV	ANT	PC
Saline nutrient solution (SNS)	4	6.5588 ^{ns}	112.97 **	0.0688 **	14.7976 **
Linear regression	1	7.5355 ^{ns}	390.014 **	0.265 **	49.1338 **
Quadratic regression	1	2.6076 ^{ns}	37.3103 **	0.0001 ^{ns}	0.5101 ^{ns}
Ascorbic acid (AA)	4	3.1674 ^{ns}	5.2190 **	0.0573 **	3.2250 ^{ns}
Linear regression	1	5.4840 ^{ns}	4.3630 **	0.0505 **	0.8141 ^{ns}
Quadratic regression	1	0.0124 ^{ns}	12.0723 **	0.1642 **	4.3152 ^{ns}
Interaction (SNS × AA)	16	4.9383 ^{ns}	1.9892 **	0.0110 **	18.1669 ^{ns}
Blocks	3	0.1060 ^{ns}	0.0682 ^{ns}	0.0014 ^{ns}	0.2835 ^{ns}
Residue	72	0.0645	0.5130	0.0039	0.3509
CV (%)		2.82	7.03	16.48	7.84

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

The increase in SNS levels led to higher contents of flavonoids (FLV, $p \leq 0.01$) and anthocyanins (ANT, $p \leq 0.01$) in cherry tomato fruits (Figure 7A,B). However, foliar spraying with 600 mg L^{-1} of ascorbic acid (AA) resulted in the lowest values of FLV (9.06 mg 100 g^{-1}) and ANT (0.06 mg 100 g^{-1}) in plants grown under an SNS of 4.9 dS m^{-1}. In contrast, plants exposed to the highest salinity level (4.9 dS m^{-1}) without AA application (0 mg L^{-1}) exhibited the highest FLV (12.97 mg 100 g^{-1}) and ANT (0.54 mg 100 g^{-1}) contents.

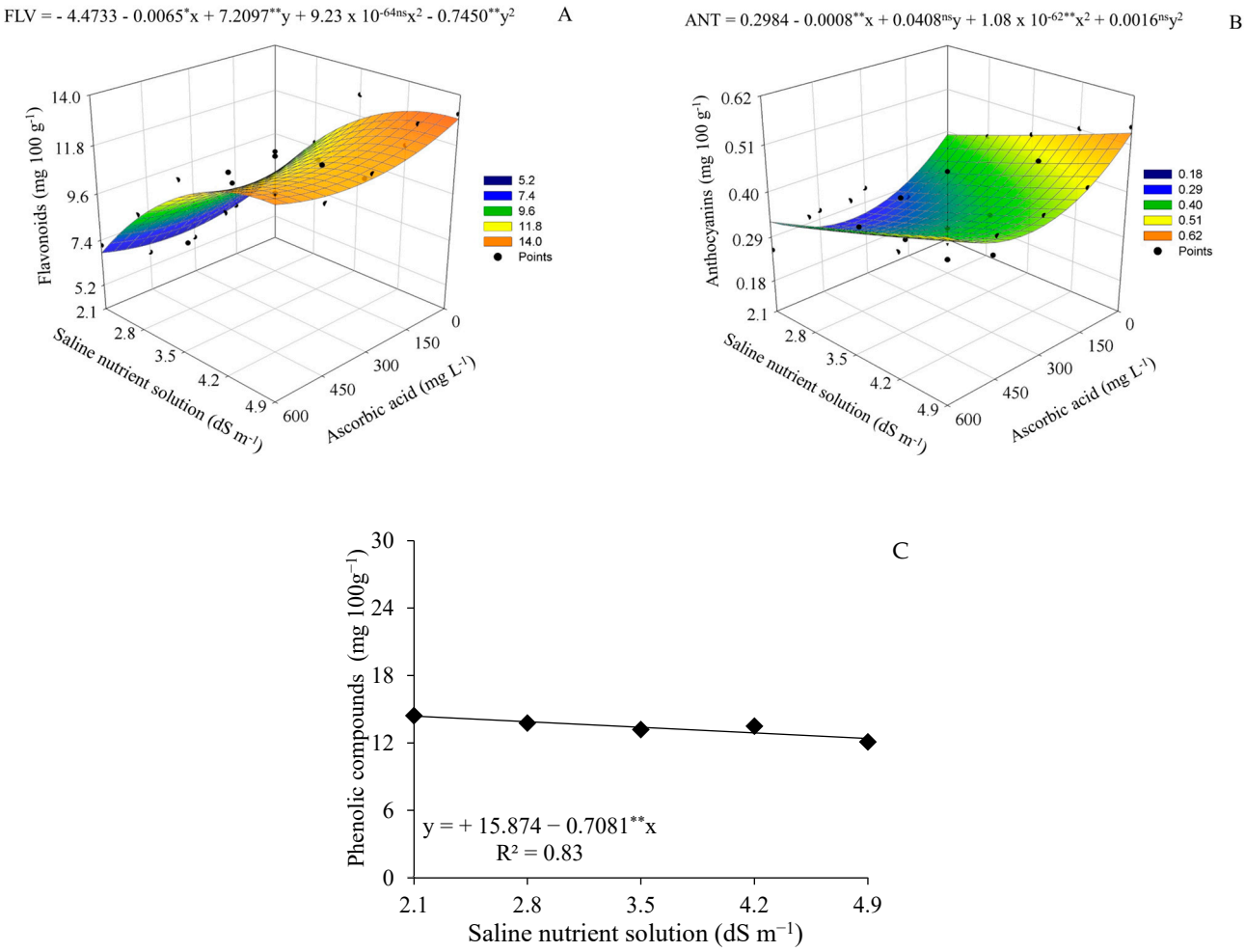

Figure 7. Flavonoids—FLV (**A**) and anthocyanins—ANT (**B**) in 'Laranja' cherry tomato fruits as a function of the interaction between saline nutrient solution electrical conductivity levels (SNS) and ascorbic acid (AA) concentrations; and phenolic compounds—PC (**C**) in cherry tomato fruits as a function of SNS levels, measured at 108 days after sowing. x and y—Ascorbic acid concentration and electrical conductivity of the saline nutrient solution (SNS), respectively. ^{ns}, * and ** not significant ($p > 0.05$) and significant at $p \leq 0.05$ and at $p \leq 0.01$ by F test, respectively

Phenolic compound (PC) contents in cherry tomato fruits decreased linearly with increasing SNS levels (Figure 7C), with a reduction of 4.46% for each unit increase in SNS. Comparing plants grown under an SNS of 2.1 dS m^{-1} with those under the highest SNS (4.9 dS m^{-1}), a 13.78% decrease in PC content was observed.

Changes in production and postharvest variables of 'Laranja' cherry tomato fruits are shown in the Pearson correlation matrix (Figure 8). A strong positive correlation (above 0.90) was observed between total yield and other yield components, such as average fruit weight (0.91), number of clusters (0.91), polar diameter (0.93), equatorial diameter (0.95), and number of fruits per plant (0.98).

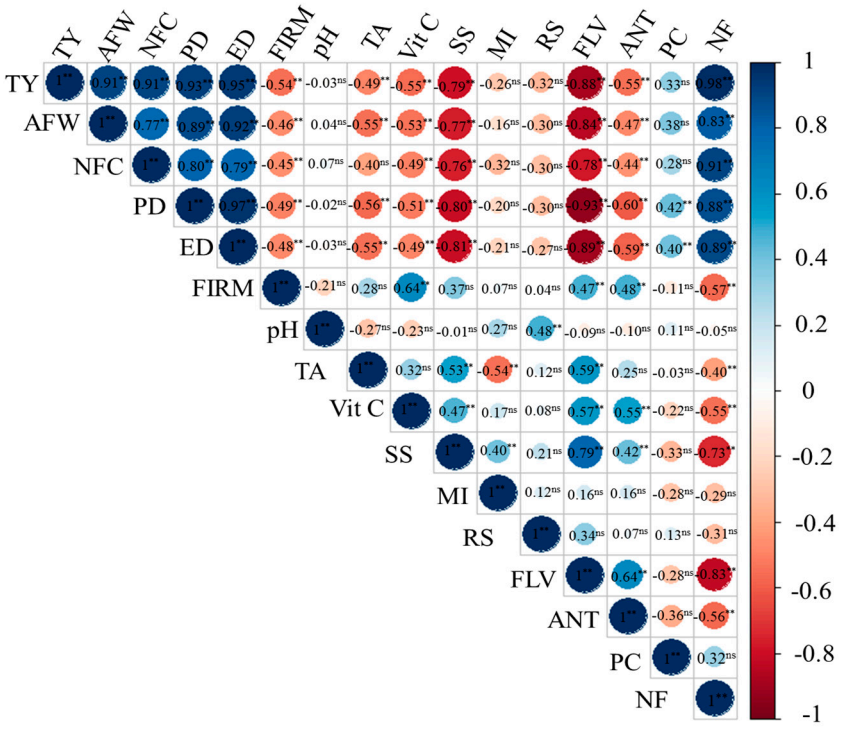

Figure 8. Pearson correlation matrix for production and postharvest quality traits of 'Laranja' cherry tomato cultivated under saline nutrient solutions, electrical conductivity levels, and foliar application of ascorbic acid. Total yield—TY (g per plant), average fruit weight—AFW (g per fruit), number of fruit clusters—NFC, polar diameter—PD (mm), equatorial diameter—ED (mm), firmness—FIRM (kgf cm^{-2}), pH, titratable acidity—TA (g 100 g^{-1}), vitamin C—Vit C (mg 100 g^{-1}), soluble solids—SS (°Brix), maturity index—MI, reducing sugars—RS, flavonoids—FLV (mg 100 g^{-1}), anthocyanins—ANT (mg 100 g^{-1}), phenolic compounds—PC (mg 100 g^{-1}), and number of fruits—NF. ^{ns} and ** not significant ($p > 0.05$) and significant at $p \leq 0.05$ and at $p \leq 0.01$ by Student's *t*-test, respectively.

When total yield was correlated with postharvest variables, significant negative correlations were found, especially with soluble solids (SS, −0.79) and flavonoids (FLV, −0.88). In addition, a strong negative correlation was observed between SS and FLV with polar diameter (PD, −0.80 and −0.93) and equatorial diameter (ED, −0.81 and −0.89), respectively.

Soluble sugar in cherry tomato fruits showed strong positive correlations with titratable acidity (TA, 0.53), vitamin C (0.47), FLV (0.79), and ANT (0.42). Fruit firmness was positively correlated with vitamin C (0.64), FLV (0.47), and ANT (0.48). It is also noteworthy that pH showed a positive correlation only with total sugars (0.48) and did not influence the other studied variables.

4. Discussion

4.1. Effects of Saline Stress on Yield Components

The use of saline water in agriculture for formulating nutrient solutions in soilless cultivation systems has been widely investigated due to the impacts of salt stress on fruit yield and postharvest quality [7,32]. The results of the present study indicate that salt stress caused by increased electrical conductivity of the nutrient solution negatively affected the yield components of cherry tomato plants. However, the use of saline nutrient solutions combined with foliar application of ascorbic acid (AA) enhanced the postharvest quality of the fruits.

Under salt stress conditions, plants experience a systemic decrease in energy due to reductions in leaf area, photosynthetic rate, and the redirection of energy toward defense

and stress tolerance mechanisms [33]. This energy reallocation has a detrimental effect on plant growth and development, as photosynthetic processes are essential for producing assimilates that are crucial for the formation of reproductive structures and fruit filling. Thus, the reductions observed in total yield (TY, Figure 3A), average fruit weight (AFW, Figure 3B), and number of clusters (NC, Figure 3C) can be explained by the effects of salt stress, which cause physiological and metabolic disturbances in the plants, compromising their yield components [34]. Roque et al. [2], in a study with the 'Cereja Vermelho' cultivar under irrigation water salinity ranging from 0.3 to 4.3 dS m^{-1} in a conventional soil-based production system, also reported significant reductions in yield components, even when using water with the lowest tested EC level (0.3 dS m^{-1}), highlighting the sensitivity of tomato crops to salinity, even under mildly saline conditions.

Furthermore, the imposition of salt stress during developmental stages in which plants are more sensitive directly influences the severity of damage. Exposure to stress during critical phases, such as flowering, can reduce fruit set by inducing flower abortion [35]. This effect was observed in the present study, where a 54.65% reduction (221 fruits per plant) was recorded when comparing plants grown under the lowest (2.1 dS m^{-1}) and highest (4.9 dS m^{-1}) salinity levels of the nutrient solution (Figure 3D). Similarly, Roque et al. [2] reported a decline in the number of cherry tomato fruits in soil-grown plants under salt stress, with irrigation water of 1.3 dS m^{-1} yielding a maximum of 158.15 fruits per plant, while higher EC levels reduced fruit production.

4.2. Modulation of Postharvest Quality by Salinity and Ascorbic Acid Application

In terms of fruit physical characteristics, according to Fernandes et al. [36], the fruits in this study are small, given their diameters were below 25 mm. Excess salts in the nutrient solution induce osmotic stress, which negatively affects water and nutrient uptake [37]. This may have contributed to the observed reductions in polar and equatorial fruit diameters (Figure 4A,B). Similar detrimental effects were reported by Guedes et al. [32], who grew cherry tomatoes in a hydroponic system under varying salinity levels (2.1, 2.8, 3.5, and 4.2 dS m^{-1}) under foliar application of hydrogen peroxide (0, 12, 24, 36, and 48 µM). They found that salinity levels from 2.1 dS m^{-1} onwards negatively affected both polar and equatorial fruit diameters.

Conversely, the present study demonstrated that foliar application of 600 mg L^{-1} ascorbic acid (AA), in combination with SNS of 4.9 dS m^{-1}, produced firmer fruits (Figure 5). Fruit firmness is a key attribute for postharvest handling, as it directly affects resistance to mechanical damage and extends shelf life [38]. These results suggest that AA may act as a modulator of cell wall integrity, preserving fruit texture even under severe salt stress. This effect may be linked to the role of AA as a cofactor for enzymes involved in hydroxyproline synthesis—a structural component of cell wall glycoproteins—and its capacity to limit pectin and cellulose degradation by mitigating reactive oxygen species (ROS) [39].

The results indicate a classic trade-off, a well-documented plant defense mechanism [40]. Under salt stress, plants often reallocate resources from biomass production (yield) toward the synthesis of protective compounds and osmolytes [41]. While this shift can reduce yield, it frequently enhances fruit quality traits. This was evident in our study, where increased salinity elevated total soluble solids (SS) and titratable acidity (TA). According to Brazilian quality standards for tomatoes [42], desirable thresholds are above 5 °Brix for SS and 4 g 100 g^{-1} for TA.

In this study, fruits from plants grown under the highest salinity level (4.9 dS m^{-1}) combined with foliar application of 600 mg L^{-1} AA met the recommended thresholds for both SS (Figure 6A) and TA (Figure 6B). This demonstrates that, despite the yield limitations imposed by salt stress, fruits of commercially acceptable quality can still be

obtained. Ascorbic acid may have potentiated this process by protecting the metabolic pathways of carbohydrate and organic acid synthesis from oxidative damage, thereby promoting greater accumulation of these compounds in the fruits [39].

Additionally, increasing the SNS up to 4.9 dS m^{-1} led to an increase in vitamin C content in the fruits (Figure 6C), which is a desirable trait. Vitamin C is one of the most important supplements for human health, with over 90% of intake derived from fruits and vegetables [43]. It also acts as a key hydrophilic antioxidant, capable of scavenging free radicals [44]. Similar increases in vitamin C content were reported by Silva et al. [45] in conventionally grown mini-watermelons under saline stress (electrical conductivity of water varying between 0.3 and 2.8 dS m^{-1}) with foliar application of hydrogen peroxide (0, 20, 40, and 60 μM). These researchers observed that irrigation with water of EC $\geq$ 1.2 dS m^{-1} enhanced vitamin C levels.

According to the results of the present study, the highest salinity level (4.9 dS m^{-1}) also resulted in increased levels of flavonoids (FLV) and anthocyanins (ANT) (Figure 7A,B). As noted by Ribeiro and Seravalli [46], during fruit ripening, chlorophyll degrades while other pigments—such as flavonoids—are synthesized, contributing to fruit quality. In the case of anthocyanins, several factors affect their stability, with pH being one of the most critical. Anthocyanin stability is higher under acidic conditions, which was confirmed in this study by the increase in titratable acidity in cherry tomato fruits sprayed with 600 mg L^{-1} AA [47].

Notably, applying the highest dose of AA (600 mg L^{-1}) under high salinity resulted in reduced flavonoid and anthocyanin levels. This likely reflects a metabolic adjustment mechanism, where the abundance of the potent exogenous antioxidant (AA) signals a decreased need for synthesizing other endogenous antioxidants [48]. Consequently, the plant may downregulate flavonoid and anthocyanin biosynthesis in the fruit to conserve energy and maintain metabolic balance under stress [49].

A reduction in total phenolic compounds was observed as the salinity level of the nutrient solution increased (Figure 7C). Phenolic compounds play an essential role in plants by acting as antioxidants and providing protection against environmental stresses, such as ultraviolet radiation and pathogen attacks [50]. Therefore, their reduction may be associated with the plant's response to salt stress, as these compounds may be utilized for defense, limiting their accumulation in the fruits [51,52].

4.3. Correlations Between Yield Parameters and Postharvest Quality

This study also revealed a strong negative correlation between fruit diameters and levels of SS and FLV, as well as with some yield components. In general, this can be explained by the fact that larger fruits contain more water, which may dilute soluble compounds, thereby reducing their concentration. Moreover, an increased number of fruits per plant can intensify competition for assimilates, further decreasing the accumulation of soluble compounds such as SS and FLV [53].

Conversely, the SS content of cherry tomato fruits showed a strong positive correlation with TA, vitamin C, FLV, and ANT. Additionally, fruit firmness was positively correlated with AA, FLV, and ANT. This relationship is attributed to the activation of tolerance mechanisms, such as the synthesis of antioxidant compounds aimed at neutralizing free radicals and protecting cells from oxidative damage induced by salt stress [54]. It was also observed that pH was positively correlated only with total sugars, a parameter associated with the physiological transformations that occur in fruits during storage and conservation processes [55].

In summary, the present study demonstrated that the application of ascorbic acid as a mitigating agent against salt stress can enable the use of saline water in substrate-

based hydroponic cultivation, particularly by improving yield and postharvest quality of 'Laranja' cherry tomato fruits. Although increasing the SNS of the nutrient solution reduces both total yield and average fruit weight, the results suggest that solutions with EC levels up to 3.5 dS m^{-1} allow for the viable use of saline water in hydroponic systems, as the production levels remain within acceptable parameters for commercial cultivation. Future research should aim to validate these findings across other tomato cultivars and diverse climatic conditions. Additionally, direct physiological and biochemical analyses—such as gas exchange measurements and antioxidant enzyme assays, are needed to provide a deeper mechanistic understanding of ascorbic acid's mode of action.

5. Conclusions

Electrical conductivity (SNS) levels of the nutrient solution from 2.1 dS m^{-1} onward reduced total yield, average fruit weight, number of clusters and fruits, polar and equatorial diameters, as well as phenolic compound content in 'Laranja' cherry tomato fruits. However, the highest level of saline nutrient solution (4.9 dS m^{-1}) combined with foliar application of ascorbic acid (AA) at 600 mg L^{-1} increased fruit firmness, soluble solids, and titratable acidity. Additionally, nutrient solution SNS levels up to 4.9 dS m^{-1} enhanced the contents of vitamin C, flavonoids, and anthocyanins in the fruits. Conversely, foliar application of 600 mg L^{-1} AA under the lowest (2.1 dS m^{-1}) reduced vitamin C, flavonoid, and anthocyanin contents in the fruits.

Based on these results, the initial hypothesis that foliar application of ascorbic acid induces salt stress tolerance mechanisms leading to increased yield is rejected. While ascorbic acid did not improve yield under saline stress, it significantly enhanced postharvest quality traits such as firmness and soluble solids. This supports its potential role in quality-focused hydroponic cultivation under saline conditions.

Further research is needed to elucidate the physiological and biochemical mechanisms by which AA may induce salt stress tolerance. Future studies should include detailed analyses linked to the crop's phenological stages to identify periods of greatest sensitivity and responsiveness to AA. Molecular approaches, such as transcriptomic profiling of AA-induced pathways, will be essential to deepen the mechanistic understanding of ascorbic acid-mediated stress tolerance.

Overall, AA represents a promising low-cost and easy-to-apply alternative for improving the postharvest quality of cherry tomatoes grown under saline water stress. Its use may contribute to sustainable utilization of saline water in substrate-based hydroponic systems, especially in semi-arid regions facing water scarcity and high salinity challenges.

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References

1. Gonçalves, D.C.; dos S. Fernandes, C.H.; Tejo, D.P.; Vidal, T.C.M. Cultivo do tomate cereja sob sistema hidropônico: Influência do turno de rega. *Uniciências* **2018**, *22*, 20–23. [CrossRef]
2. Roque, I.A.; dos A. Soares, L.A.; de Lima, G.S.; Lopes, I.A.P.; de A. Silva, L.; Fernandes, P.D. Biomass, gas exchange and production of cherry tomato cultivated under saline water and nitrogen fertilization. *Rev. Caatinga* **2022**, *35*, 686–696. [CrossRef]
3. IBGE—Instituto Brasileiro de Geografia e Estatística. Produção Agrícola Municipal 2023. Available online: https://www.ibge.gov.br/explica/producao-agropecuaria/tomate/br (accessed on 8 September 2024).
4. Nóbrega, J.S.; Guedes, M.A.; de Lima, G.S.; Gheyi, H.R.; dos A. Soares, L.A.; de A. Silva, L.; da Silva, S.S.; de A. Brito, L. Photosynthetic pigments, growth, and production of cherry tomato under salt stress and hydrogen peroxide. *Rev. Bras. Eng. Agric. Ambient.* **2024**, *28*, e275968. [CrossRef]
5. Andrade, E.M.G.; de Lima, G.S.; de Lima, V.L.A.; da Silva, S.S.; Dias, A.S.; Gheyi, H.R. Hydrogen peroxide as attenuator of salt stress effects on the physiology and biomass of yellow passion fruit. *Rev. Bras. Eng. Agrícola Ambient.* **2022**, *26*, 571–578. [CrossRef]
6. Wang, Y.; Cao, Y.; Liang, X.; Zhuang, J.; Wang, X.; Qin, F.; Jiang, C. A dirigent family protein confers variation of Casparian strip thickness and salt tolerance in maize. *Nat. Commun.* **2022**, *13*, 2222–2239. [CrossRef] [PubMed]
7. Oliveira, V.K.N.; da Silva, A.A.R.; de Lima, G.S.; dos A. Soares, L.A.; Gheyi, H.R.; de Lacerda, C.F.; de Azevedo, C.A.V.; Nobre, R.G.; Chaves, L.H.G.; Fernandes, P.D.; et al. Foliar application of salicylic acid mitigates saline stress on physiology, production, and post-harvest quality of hydroponic *Japanese cucumber*. *Agriculture* **2023**, *13*, 395. [CrossRef]
8. Chen, L.; Meng, Y.; Yang, W.; Qian, L.V.; Zhou, L.; Liu, S.; Li, X. Genome-wide analysis and identification of TaRING-H2 gene family and TaSDIR1 positively regulates salt stress tolerance in wheat. *Int. J. Biol. Macromol.* **2023**, *242*, 125–162. [CrossRef]
9. Sausen, D.F.; Lopes, C.; Marques, S.; Souza, L.; Alves, A.; Patrocínio, E.; Cordeiro, E.K. Cultivo fora do solo: Uma alternativa para áreas marginais. *Braz. J. Dev.* **2020**, *6*, 14888–14903. [CrossRef]
10. Wendling, I.; Ferrari, M.P.; Dutra, L.F. *Produção de Mudas de Corticeira-do-Mato por Miniestaquia a Partir de Propágulos Juvenis*; Embrapa Florestas: Colombo, Sri Lanka, 2005; 5p.
11. Hutchinson, G.K.; Nguyen, L.X.; Ames, Z.R.; Nemali, K.; Ferrarezi, R.S. Substrate system outperforms water-culture systems for hydroponic strawberry production. Front. *Plant Sci.* **2025**, *16*, 1469430.
12. Martínez, J.P.; Fuentes, R.; Farías, K.; Lizana, C.; Alfaro, J.F.; Fuentes, L.; Lutts, S. Effects of salt stress on fruit antioxidant capacity of wild (*Solanum chilense*) and domesticated (*Solanum lycopersicum* var. cerasiforme) tomatoes. *Agronomia* **2020**, *10*, 1481. [CrossRef]
13. Caetano, E.J.M.; da Silva, A.A.R.; de Lima, G.S.; de Azevedo, C.A.V.; de Veloso, L.L.S.A.; de Arruda, T.F.L.; de Souza, A.R.; dos Soares, L.A.A.; Gheyi, H.R.; dos Dias, M.S.; et al. Application techniques and concentrations of ascorbic acid to reduce saline stress in passion fruit. *Plants* **2024**, *13*, 2718. [CrossRef] [PubMed]
14. El-Beltagi, H.S.; Ahmad, I.; Basit, A.; Shehata, W.F.; Hassan, U.; Shah, S.T.; Ullah, A.; Mohamed, H.I. Ascorbic acid enhances growth and yield of sweet peppers (*Capsicum annum*) by mitigating salinity stress. *Gesunde Pflanz.* **2022**, *74*, 423–433. [CrossRef]
15. Chen, X.; Jiang, Y.; Cong, Y.; Liu, X.; Yang, Q.; Xing, J.; Liu, H. Ascorbic acid mitigates salt stress in tomato seedlings by enhancing chlorophyll synthesis pathways. *Agronomy* **2024**, *14*, 1810. [CrossRef]
16. Kamran, A.; Mushtaq, M.; Arif, M.; Rashid, S. Papel dos bioestimulantes (ácido ascórbico e ácido fúlvico) para sinergizar a atividade do *Rhizobium* na ervilha (*Pisum sativum* L. var. Meteor). *Plant Physiol. Biochem.* **2023**, *196*, 668–682. [CrossRef] [PubMed]
17. Celi, G.E.A. Uso de Ácido Ascórbico em Plantas de Soja Submetidas à Salinidade. Dissertação Thesis, Universidade Estadual Paulista, Unesp, Jaboticabal, 25 March 2022.
18. Naz, S.; Mushtaq, A.; Ali, S.; Muhammad, H.M.D.; Saddiq, B.; Ahmad, R.; Shahzad, M.; Ayaz, A.; Aamir, M.; Al-Saeed, F.A.; et al. Foliar application of ascorbic acid enhances growth and yield of lettuce (*Lactuca sativa*) under saline conditions by improving antioxidant defence mechanism. *Funct. Plant Biol.* **2024**, *51*, 43–55. [CrossRef] [PubMed]
19. Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; de Gonçalvez, J.D.; Sparovek, G. Köppen's climate classification map for Brazil. *Meteorol. Z.* **2013**, *22*, 711–728. [CrossRef] [PubMed]
20. Guedes, M.A.; Gheyi, H.R.; de Lima, G.S.; dos A. Soares, L.A.; Sa, V.K.N.O.; Silva, L.A.; Silva, F.J.L.; Torres, R.A.F. Aplicação foliar de H_2O_2 no cultivo hidropônico de tomate cereja sob soluções nutritivas salinas. *WRIM* **2024**, *13*, 150–164.

21. Gaafar, A.A.; Ali, S.I.; El-Shawadfy, M.A.; Salama, Z.A.; Sękara, A.; Ulrichs, C.; Abdelhamid, M.T. Ascorbic acid induces the increase of secondary metabolites, antioxidant activity, growth, and productivity of the common bean under water stress conditions. *Plants* **2020**, *9*, 627. [CrossRef] [PubMed]
22. Agristar—Instituto de Ação Social. Available online: https://agristar.com.br/topseed-garden/blue-linehortalicas/tomate-cereja-laranja/1888147 (accessed on 9 October 2024).
23. Hoagland, D.R.; Arnon, D.I. The water-culture method for growing plants without soil. *Calif. Agric. Exp. Stn. Bull.* **1950**, *347*, 1–32.
24. Richards, L.A. *Diagnosis and Improvement of Saline and Alkali Soils*; U.S. Department of Agriculture USDA Handbook: Washington, DC, USA, 1954; Volume 60, 160p.
25. IAL—Instituto Adolfo Lutz. *Normas analíticas do Instituto Adolfo Lutz*, 4th ed.; IAL: São Paulo, Brasil, 2008; pp. 102–104.
26. Strohecker, R.R.; Henning, H.M. *Analises de Vitaminas: Métodos Comprobados*; Editora Paz Montalvo: Madrid, Spain, 1967; 428p.
27. Benassi, M.T.; Antunes, A.J. A comparison of meta-phosphoric and oxalic acids as extractant solutions for the determination of vitamin C in selected vegetables. *Braz. Arch. Biol. Technol.* **1988**, *31*, 507–513.
28. Vasconcelos, N.M.; Pinto, G.A.S.; Aragão, F.A.S. *Determinação de Açúcares Redutores pelo Ácido 3,5-Dinitrosalicílico: Histórico do Desenvolvimento do Método e Estabelecimento de um Protocolo Para o Laboratório de Bioprocessos*; Embrapa Agroindústria Tropical: Fortaleza, Brazil, 2013; 29p.
29. Francis, F.J. Analysis of anthocyanins. In *Anthocyanins as Food Colors*; Markakis, P., Ed.; Academic Press: New York, NY, USA, 1982; pp. 182–205.
30. Waterhouse, A. Folin-ciocalteau micro method for total phenol in wine. *AJEV* **2006**, *11*, 3–5.
31. Ferreira, D.F. Sisvar: A computer analysis system to fixed effects split-plot type designs. *Rev. Bras. Biom.* **2019**, *37*, 529–535. [CrossRef]
32. Guedes, M.A.; Silva, A.A.R.; Lima, G.S.; Gheyi, H.R.; Soares, L.A.A.; Silva, L.A.; Oliveira, V.K.N.; Fatima, R.T.; Nobre, R.G.; Nobrega, J.S.; et al. Hydroponic cultivation of laranja cherry tomatoes under salt stress and foliar application of hydrogen peroxide. *Agriculture* **2023**, *13*, 1688. [CrossRef]
33. Liang, H.; Shi, Q.; Li, X.; Gao, P.; Feng, D.; Zhang, X.; Ma, W. Synergistic effects of carbon cycle metabolism and photosynthesis in Chinese cabbage under salt stress. *Hortic. Plant J.* **2022**, *9*, 1–12. [CrossRef]
34. Zhao, Y.; Jia, K.; Tian, Y.; Han, K.; El-Kassaby, Y.A.; Yang, H.; Li, Y. Timecourse transcriptomics analysis reveals key responses of populus to salt stress. *Ind. Crops Prod.* **2023**, *194*, 116–178. [CrossRef]
35. Santos, C.A.; Carmo, M.G.F.; Abboud, A.C.S. Novo nicho: Tomate cereja orgânico. *Campo Negócios HF* **2016**, *137*, 16–20.
36. Fernandes, C.; Corá, J.E.; Braz, L.T. Classificação de tomate-cereja em função do tamanho e peso dos frutos. *Hortic. Bras.* **2007**, *25*, 275–278. [CrossRef]
37. Skider, R.K.; Wang, X.; Zhang, H.; Gui, H.; Dong, Q.; Jin, D.; Song, M. Nitrogen enhances salt tolerance by modulating the antioxidant defense system and osmoregulation substance content in *Gossypium hirsutum*. *Plants* **2020**, *9*, 450. [CrossRef] [PubMed]
38. de S. Viana, E.; Reis, R.C.; da Ronielli Cardoso, S.C.S.; das Neves, T.T.; de Jesus, J.L. Avaliação físico-química e sensorial de frutos de genótipos melhorados de mamoeiro. *Pesqui. Agropecu. Trop.* **2015**, *45*, 297–303. [CrossRef]
39. Wu, P.; Li, B.; Liu, Y.; Bian, Z.; Xiong, J.; Wang, Y.; Zhu, B. Multiple physiological and biochemical functions of ascorbic acid in plant growth, development, and abiotic stress response. *Int. J. Mol. Sci.* **2024**, *25*, 1832. [CrossRef]
40. Figueroa-Macías, J.P.; Ceballos-García, Y.; Núñez, M.; Díaz, K.; Olea, A.F.; Espinoza, L. Plant growth-defense trade-offs: Molecular processes leading to physiological changes. *Int. J. Mol. Sci.* **2021**, *22*, 693. [CrossRef] [PubMed]
41. Azeem, M.; Pirjan, K.; Qasim, M.; Mahmood, A.; Javed, T.; Muhammad, H.; Yang, S.; Dong, R.; Ali, B.; Rahimi, M. Salinity stress improves antioxidant potential by modulating physio-biochemical responses in Moringa oleifera Lam. *Sci. Rep.* **2023**, *13*, 2895. [CrossRef]
42. Brasil Ministério da Agricultura e do Abastecimento. *Aprova o Regulamento Técnico Geral Para Fixação dos Padrões de Identidade e Qualidade Para Polpa de Fruta*; Diário Oficial da União: Brasília, Brazil, 2018; 23p.
43. Lee, S.K.; Kader, A.A. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* **2020**, *20*, 207–220. [CrossRef]
44. Zamuz, S.; Munekata, P.E.S.; Gullón, B.; Rocchetti, G.; Montesano, D.; Lorenzo, J.M. Citrullus lanatus as source of bioactive components: An up-to-date review. *Trends Food Sci. Technol.* **2021**, *111*, 208–222. [CrossRef]
45. Da Silva, F.J.L.; de Lima, G.S.; da Silva, S.S.; dos A. Soares, L.A.; Torres, R.A.F.; Gheyi, H.R.; da Silva, J.S.; Mendonça, A.J.T.; Andrade, J.T.F.; da Silva, A.A.R.; et al. Effect of hydrogen peroxide application on physiology, production, and post-harvest quality of mini watermelon under salt stress. *Arid Land Res. Manag.* **2024**, *38*, 262–288.
46. Ribeiro, E.P.; Seravalli, E.A.G. *Química dos Alimentos*, 2nd ed.; Editora Blucher: São Paulo, Brazil, 2007; 196p.
47. Modesto Junior, E.N.; da S. Soares, S.; Gomes, P.W.P.; Ribeiro, C.D.F.A.; da Silva, R.M.V. Estudo do armazenamento da polpa do fruto ginja *Eugenia uniflora* L. e sua influência nos teores de ácido ascórbico e antocianinas. *Sci. Plena* **2016**, *12*, 1–8. [CrossRef]

48. Hasanuzzaman, M.; Bhuyan, M.B.; Anee, T.I.; Parvin, K.; Nahar, K.; Mahmud, J.A.; Fujita, M. Regulation of ascorbate-glutathione pathway in mitigating oxidative damage in plants under abiotic stress. *Antioxidants* **2019**, *8*, 384. [CrossRef] [PubMed]
49. Baskar, V.; Venkatesh, R.; Ramalingam, S. Flavonoids (antioxidant systems) in higher plants and their response to stresses. In *Antioxidants and Antioxidant Enzymes in Higher Plants*; Gupta, D.K., Palma, J.M., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 253–268.
50. UFRA-Universidade Federal Rural de Amazonas. *Cartilha de Alimentos Funcionais: A Ciência no Seu Prato: Compostos Fenólicos e Flavonoides*; Pará: Bélem, Brazil, 2024; 16p.
51. González-García, Y.; Cárdenas-Álvarez, C.; Cadenas-Pliego, G.; Benavides-Mendoza, A.; Cabrera-De-La-Fuente, M.; Sandoval-Rangel, A.; Valdés-Reyna, J.; Juárez-Maldonado, A. Effect of three nanoparticles (Se, Si and Cu) on the bioactive compounds of bell pepper fruits under saline stress. *Plants* **2021**, *10*, 217. [CrossRef] [PubMed]
52. Ahlawat, Y.K.; Singh, M.; Manorama, K.; Lakra, N.; Zaid, A.; Zulfiqar, F. Plant phenolics: Neglected secondary metabolites in plant stress tolerance. *Braz. J. Bot* **2024**, *47*, 703–721. [CrossRef]
53. Queiroga, R.C.F.; Puiatti, M.; Fontes, P.C.R.; Cecon, P.R. Produtividade e qualidade do melão cantaloupe, cultivado em ambiente protegido, variando o número e a posição dos frutos na planta. *Bragantia* **2008**, *67*, 911–920. [CrossRef]
54. Souza, A.V.D.; Vieira, M.R.D.S.; Putti, F.F. Correlações entre compostos fenólicos e atividade antioxidante em casca e polpa de variedades de uva de mesa. *BJFT* **2018**, *21*, e2017103. [CrossRef]
55. Gouveia, A.M.F.Q. Qualidade Pós-Colheita dos Frutos de Passiflora cincinnata Armazenados sob Refrigeração. Dissertação Thesis, Universidade Federal de Campina Grande, Pombal, Portugal, 14 March 2023.