Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Ascorbic ACID Modulates the Tolerance of Sour Passion Fruit to Salt Stress During the Seedling Formation Stage

Espedita Ranily Inácio da Silva
Federal University of Campina Grande
Carlos Augusto Mota soares
Federal University of Campina Grande
Allesson Ramos de Souza
allesson.ramos@estudante.ufcg.edu.br

Federal University of Campina Grande
Geovani Soares de Lima
Federal University of Campina Grande
Lauriane Almeida dos Anjos Soares
Federal University of Campina Grande
Lucyelly Dâmela Araújo Borborema
Federal University of Campina Grande
Flávia de Sousa Almeida
Federal University of Campina Grande
Vitor Manoel Bezerra da Silva
Federal University of Campina Grande
Valéria Fernandes de Oliveira Sousa
Federal University of Campina Grande
Saulo Soares da Silva
Federal University of Campina Grande
Jackson Silva Nóbrega
Federal University of Oeste do Pará
Reynaldo Teodoro de Fatima
Federal University of Campina Grande

Research Article

Keywords: Passiflora edulis Sims, elicitor, abiotic stress, non-enzymatic

Posted Date: April 28th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9362043/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

ASCORBIC ACID MODULATES THE TOLERANCE OF SOUR PASSION FRUIT TO SALT STRESS DURING THE SEEDLING FORMATION STAGE

Espedita Ranily Inácio da Silva[1], Carlos Augusto Mota soares[1], Allesson Ramos de Souza[*2], Geovani Soares de Lima[1], Lauriane Almeida dos Anjos Soares[1], Lucyelly Dâmela Araújo Borborema[2], Flávia de Sousa Almeida[1], Vitor Manoel Bezerra da Silva[2], Valéria Fernandes de Oliveira Sousa[1], Saulo Soares da Silva[1], Jackson Silva Nóbrega[3,] Reynaldo Teodoro de Fatima[1].

1 Federal University of Campina Grande, Centro de Ciências e Tecnologias Agroalimentar, Pombal-PB 58840-000, Paraíba, Brazil;
2 Federal University of Campina Grande, Academic Unit of Agricultural Engineering, Campina Grande 58429-900, Paraíba, Brazil;
3 Federal University of Oeste do Pará, Santarém 68040-255, Pará, Brazil;
* Corresponding author: allesson.ramos@estudante.ufcg.edu.br; Tel.: +55 (83) 99387-0752

ABSTRACT: In regions where climatic conditions favor soil and water salinization, characterized by high temperatures and irregular rainfall distribution over time and space, the development and expansion of passion fruit cultivation become limited. Therefore, the adoption of strategies capable of mitigating the effects of salinity on crops becomes necessary. The objective of this study was to evaluate the effect of ascorbic acid application on the physiology, growth, quality, and tolerance of sour passion fruit seedlings (Passiflora edulis Sims) cv. BRS GA1 under salt stress. The treatments consisted of five levels of electrical conductivity of irrigation water – ECw (0.3, 1.3, 2.3, 3.3, and 4.3 dS m^{-1}) and four concentrations of ascorbic acid – AsA (0, 120, 240, and 360 mg L^{-1}), arranged in a randomized block design in a 5 × 4 factorial scheme, with four replicates and two plants per plot. The increase in irrigation water salinity up to 4.3 dS m^{-1} compromised the growth and physiological performance of sour passion fruit seedlings. However, foliar application of ascorbic acid at concentrations between 240 and 300 mg L^{-1} favored the maintenance of water content, cellular integrity, and seedling growth even under higher electrical conductivity levels in irrigation water. The use of ascorbic acid at appropriate concentrations proved to be an efficient strategy for the production of sour passion fruit seedlings under saline conditions. Sour passion fruit cv. BRS GA1 is sensitive to irrigation water salinity, with a threshold level of 0.75 dS m^{-1}.

KEYWORDS: *Passiflora edulis* Sims; elicitor; abiotic stress; non-enzymatic.

1 Introduction

Passion fruit (*Passiflora edulis* Sims) is widely cultivated in tropical and subtropical regions, with fruits intended both for fresh consumption and for industrial processing (Lima et al. 2020). In Brazil, yellow passion fruit, also known as sour passion fruit, is the species with the greatest commercial relevance, despite the expressive genetic diversity present in the Passifloraceae family and the potential use of other species that remain poorly explored (Silva et al. 2025a).

In 2024, the national production of passion fruit reached 736,585 tons, with the Northeast region accounting for approximately 68.80% of this total, confirming its importance for the productive sector. However, this significant participation contrasts with the low regional average yield (14.76 kg ha^{-1}), which is lower than that observed in other regions of the country (IBGE 2024). This discrepancy indicates that, despite the high production volume, significant limitations in cultivation still persist. Much of these constraints are associated with the edaphoclimatic characteristics of the Northeast region, which is marked by high rainfall irregularity, high evaporation rates, and young soils frequently rich in soluble salts, factors that impose considerable challenges to agricultural development (Pinheiro et al. 2022; Silva et al. 2021).

Excess salts in the soil solution and/or irrigation water compromise water absorption by plants due to the reduction in soil osmotic potential, in addition to inducing ionic toxicity, resulting in changes in metabolic pathways and damage to crop development (Muhammad et al. 2024). Salt stress may reduce chlorophyll and protein contents as well as relative water content, thereby impairing essential physiological processes and limiting the initial establishment of plants (Karimi et al. 2025), especially during the seedling formation stage. The excess of salts in the soil promotes excessive accumulation of Na^+ in plant tissues, a process that intensifies the production of reactive oxygen species (ROS) and stimulates the overproduction of abscisic acid (ABA), triggering physiological imbalances that affect plant growth and productive performance (Ikram et al. 2025).

In passion fruit cultivation, the use of brackish water compromises its biochemical and physiological characteristics (Macêdo et al. 2025), affecting gas exchange, relative water content, electrolyte leakage, as well as plant growth and biomass accumulation (Silva et al. 2025a). Given this scenario, the use of substances capable of mitigating the effects of abiotic stresses has been widely investigated, with particular emphasis on ascorbic acid (AsA), whose application has proven to be a promising strategy to attenuate the impacts of salinity (Mishra et al. 2024).

In plants, ascorbic acid acts in the non-enzymatic antioxidant metabolism, reducing oxidative stress, limiting lipid peroxidation, and favoring nutrient absorption, which contributes to plant development under abiotic stress conditions (Henschel et al. 2023). In addition, AsA plays a regulatory role in photosynthetic enzymes and stimulates the biosynthesis of antioxidants, promoting the neutralization of reactive oxygen species (ROS) (El-Beltagi et al. 2022). Studies have reported the beneficial effect of exogenous application of ascorbic acid in plants subjected to salt stress, improving the antioxidant and nutritional systems in sweet pepper (*Capsicum annuum*) (Wang et al. 2019), the physiology of okra (*Abelmoschus esculentus*) (Alayafi 2020), the morphophysiology of tomato (*Solanum lycopersicum*) (El-Beltagi et al. 2022), and in guava seedlings (*Psidium guajava* L.) (Silva et al. 2025b). However, studies addressing the application of ascorbic acid during the seedling formation stage of sour passion fruit cv. BRS GA1 under salt stress are still scarce in the literature.

Considering that irrigation water salinity is one of the main limiting factors for the production and formation of sour passion fruit seedlings, especially under the semiarid conditions of Northeast Brazil, this study is based on the hypothesis that the application of ascorbic acid increases plant tolerance to salt stress by improving photosynthetic efficiency, favoring the maintenance of plant water status, and reducing the effects of salt accumulation in leaf tissues, resulting in greater growth and vigor of seedlings irrigated with brackish water. Therefore, this study aimed to evaluate the effects of ascorbic acid application on the physiology, growth, quality, and tolerance of sour passion fruit seedlings cv. BRS GA1 under salt stress cultivated in the semiarid region of Northeast Brazil.

2 Materials and methods

2.1 Experimental location

The study was conducted under protected conditions from February 24 to May 5, 2025, at the Center for Science and Agri-Food Technology (CCTA) of the Federal University of Campina Grande (UFCG), located in the municipality of Pombal, Paraiba, Brazil, at geographic coordinates 6°47′20″ S latitude and 37°48′01″ W longitude, at an altitude of 194 m. Air temperature and relative humidity data inside the protected environment were recorded using a digital thermo-hygrometer (Pro Hygro Thermo, Garden HighPro). These data are presented in Fig. 1.

.

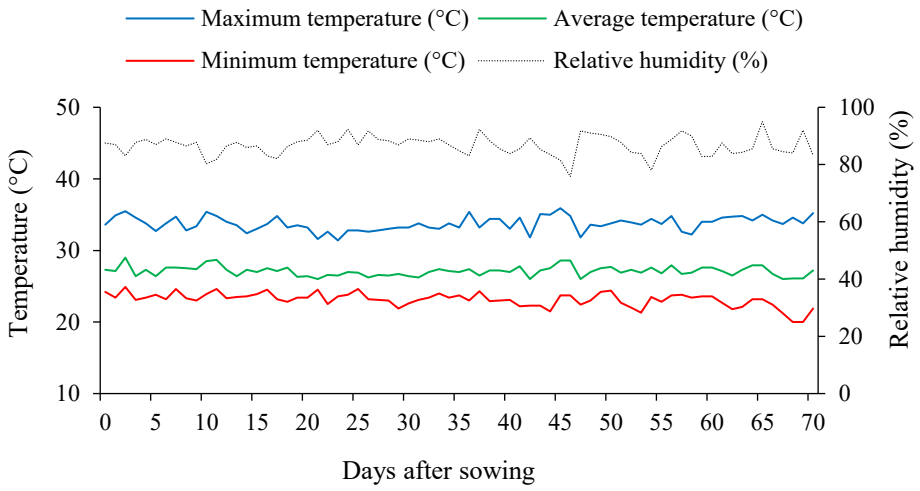


Fig. 1 Maximum, mean, and minimum temperatures and relative air humidity recorded during the period from February 24 to May 5, 2025.

2.2 Treatments and Experimental Design

The treatments consisted of five levels of electrical conductivity of irrigation water – ECw (0.3, 1.3, 2.3, 3.3, and 4.3 dS m^{-1}) and four concentrations of ascorbic acid – AsA (0, 120, 240, and 360 mg L^{-1}), arranged in a randomized block design in a 5 × 4 factorial scheme, with four replicates and two plants per plot, totalling 160 experimental units. The electrical conductivity levels of irrigation water were adapted

from studies conducted by Souza et al. (2025) with sour passion fruit (*Passiflora edulis* Sims). The concentrations of ascorbic acid were based on and adapted according to the study conducted by Lacerda et al. (2025) with guava (*Psidium guajava* L.).

The cultivar used was BRS Gigante Amarelo F1 (BRS GA1), which presents characteristics such as yellow-colored fruits with an oblong shape, slightly flattened at the base and apex, and an average fruit weight ranging from 120 to 350 g. It also presents an approximate pulp yield of 40% (Embrapa, 2008).

The seedlings were produced in plastic bags measuring 30 cm in height and 12 cm in diameter, filled with soil collected from the 0–30 cm layer at the Experimental Farm of the Center for Science and Agri-Food Technology (CCTA) of the Federal University of Campina Grande (UFCG), located in the municipality of São Domingos, Paraiba, Brazil. Subsequently, chemical and physical soil attributes were determined before the beginning of the experiment according to the methodology proposed by Teixeira et al. (2017).

The soil analysis indicated a pH of 7.19. The organic matter content was 14 g dm^{-3}, and the phosphorus (P) concentration was 59.5 mg dm^{-3}. The soil was classified as sandy loam. The exchangeable cation contents were as follows: potassium (K) = 0.49 cmolc kg^{-1}, sodium (Na) = 0.07 cmolc kg^{-1}, calcium (Ca^{2+}) = 4.7 cmolc kg^{-1}, magnesium (Mg^{2+}) = 2.63 cmolc kg^{-1}. Regarding soil acidity-related elements: aluminum (Al^{3+}) = 0 cmolc kg^{-1} and hydrogen plus aluminum ($H^{+} + Al^{3+}$) = 0 cmolc kg^{-1}. Concerning soil physical properties, the particle-size distribution consisted of: 73.51 g kg^{-1} sand, 20.14 g kg^{-1} silt and 6.35 g kg^{-1} clay. Soil bulk density was 1.2 g cm^{3+}.

Before sowing, soil moisture was adjusted to near field capacity using supply water with electrical conductivity of 0.3 dS m^{-1}. Subsequently, two seeds were sown in each plastic bag at a depth of 3 cm, spaced equidistantly. When germination began, thinning was carried out, maintaining only the most vigorous plant in each container.

Nitrogen, phosphorus, and potassium fertilization was carried out according to the recommendation of Novais et al. (1991), applying 100, 300, and 150 mg kg^{-1} of soil of N, P_2O_5, and K_2O, respectively, using urea (45% N), monoammonium phosphate ($NH_4H_2PO_4$, 12% N and 54% P_2O_5), and KCl (60% K_2O). Fertilization began 15 days after seedling emergence, and fertilizers were applied via fertigation, divided into three applications at 15-day intervals, supplying 0.24 g, 1.6 g, and 0.9 g of NPK per plant, respectively.

The ascorbic acid solutions were prepared at the time of application by dissolving the compound in distilled water according to each treatment. A nonionic surfactant adhesive (Wil Fix®) was added at a concentration of 0.5 mL L^{-1} in all treatments in order to reduce runoff of the product, allowing greater adhesion to the leaf blade and promoting greater foliar absorption. The first application of ascorbic acid was performed 30 days after sowing, and subsequent applications were carried out every 15 days, totaling three applications during the experimental period. Foliar spraying with AsA was performed in the afternoon (5:00 pm), spraying both the abaxial and adaxial surfaces of the leaves using a manual sprayer. To prevent solution drift and contact with other plants, the plants were individually isolated during spraying.

Irrigation was carried out daily, maintaining substrate moisture close to field capacity. The volume of water applied to each container was determined based on the water balance of the root zone, estimated

using the drainage lysimetry method, according to the procedure described by Bernardo et al. (2008). Irrigation with saline water began at 32 days after sowing (DAS).

Saline solutions were prepared by dissolving NaCl, $CaCl_2 \cdot 2H_2O$, and $MgCl_2 \cdot 6H_2O$ in local supply water (0.3 dS m^{-1}) at a proportion of 7:2:1, representative of the main water sources used for irrigation in the Northeast region of Brazil (Medeiros, 1992). The relationship between the electrical conductivity of irrigation water (ECw) and salt concentration was established according to the method proposed by Richards (1954).

2.3 Evaluated variables

To evaluate the effect of the treatments on sour passion fruit seedlings, the following variables were analysed: relative water content (RWC), electrolyte leakage (EL), gas exchange, photosynthetic pigments, plant growth, and the Dickson Quality Index (DQI). Leaf relative water content (RWC) was determined using four leaf discs (113 cm^2) collected from the middle third of the plant, according to the methodology proposed by Weatherley (1950). Electrolyte leakage (EL%) was measured according to the methodology adapted from Scotti-Campos et al. (2013).

Gas exchange measurements included stomatal conductance (*gs*) (mol H_2O m^{-2} s^{-1}), transpiration (*E*) (mmol H_2O m^{-2} s^{-1}), internal CO_2 concentration (*Ci*) (µmol CO_2 m^{-2} s^{-1}), and CO_2 assimilation rate (*A*) (µmol CO_2 m^{-2} s^{-1}). From these data, instantaneous carboxylation efficiency ($CEi = A/Ci$) [(µmol m^{-2} s^{-1})(µmol m^{-2} s^{-1})$^{-1}$] and instantaneous water use efficiency ($WUEi = A/E$) [(µmol m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$] were calculated. Measurements were performed using an infrared gas analyzer (IRGA) (LCpro+) during the morning period at 7:00 a.m. using the third fully expanded leaf counted from the apical bud under natural air temperature and CO_2 concentration conditions. An artificial radiation source of 1200 µmol m^{-2} s^{-1} was used, determined according to the photosynthetic light response curve.

For photosynthetic pigments, chlorophyll *a*, *b*, and total chlorophyll indices were obtained using a non-destructive method with a portable chlorophyll meter (ClorofiLOG®, model CFL 2060, Porto Alegre, RS, Brazil), with values expressed as Falker Chlorophyll Index (FCI).

Plant growth was evaluated through plant height (PH, cm), measured with a graduated ruler from the plant collar to the insertion of the apical bud; stem diameter (SD, mm), measured with a digital calliper at 2 cm above the soil surface; and number of leaves (NL), obtained by manual counting considering leaves longer than 3 cm. Leaves, stems, and roots from all plants were collected and properly identified to determine leaf dry mass (LDM, g per plant), stem dry mass (SDM, g per plant), dry mass of the aerial part (DMAP, g per plant), determined by the sum of leaf and stem dry mass, root dry mass (RDM, g per plant), and total dry mass (TDM), obtained by the sum of shoot and root dry mass. The root-to-shoot ratio (RSR) was determined by the ratio between root dry mass and shoot dry mass. Drying was carried out in a forced-air circulation oven at 70 °C until constant weight was reached.

Seedling quality was evaluated using the Dickson Quality Index (DQI) (Dickson et al. 1960), based on plant height (PH), stem diameter (SD), total dry mass (TDM), dry mass of the aerial part (DMAP), and root dry mass (RDM).

Salt tolerance of sour passion fruit cv. BRS GA1 during the seedling formation stage was determined based on the relative accumulation of total dry mass per plant, using the plateau model with

linear decrease proposed by Maas & Hoffman (1977). Model parameters were estimated by minimizing the sum of squared errors using the Solver tool in Microsoft Excel, according to Bione et al. (2021).

The data were subjected to normality tests (Shapiro–Wilk) and homogeneity of variance tests (Levene). When significance was detected ($p \leq 0.05$), an F test was applied for the factors ECw and ascorbic acid concentrations. When a significant effect was identified, linear and/or quadratic regression models were fitted. In cases where significant interaction between the factors occurred, response surface graphs were generated using SigmaPlot (version 14.5). Subsequently, Pearson correlation analysis ($p \leq 0.05$) was performed for the evaluated variables. A principal component analysis (PCA) was also conducted, retaining only variables with correlation coefficients above 0.60. All statistical analyses were performed using RStudio (version 4.1.0), with the packages AgroR, ggcorrplot, and mclust.

3 Results

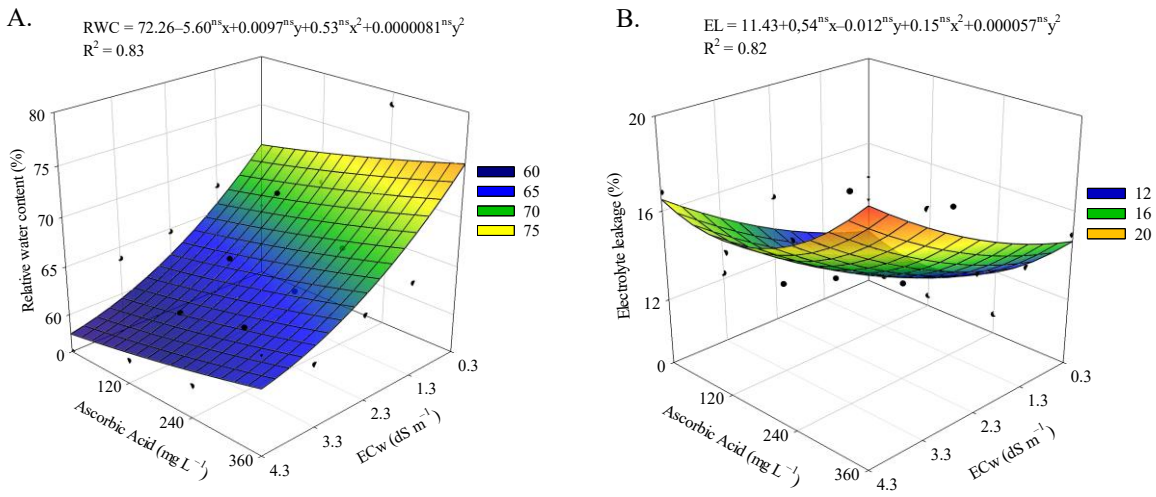
A significant interaction effect between irrigation water electrical conductivity (ECw) and ascorbic acid concentrations (AsA) ($p \leq 0.05$) was observed for relative water content (RWC) and electrolyte leakage (EL) in the leaf blade of sour passion fruit seedlings cv. BRS GA1 at 70 days after sowing (DAS) (Table 1).

Table 1. Summary of the analysis of variance for relative water content (RWC) and electrolyte leakage (EL) in the leaf blade of sour passion fruit seedlings cv. BRS GA1 cultivated under different electrical conductivity levels of irrigation water and foliar application of ascorbic acid, at 70 days after sowing (DAS).

Source of variation	DF	Mean squares	
		RWC	EL
Eletrical conductivity of irrigation water (ECw)	4	424.59^{***}	61.72^{***}
Linear regression	1	344.45^{**}	70.54^{***}
Quadratic regression	1	7.12^{ns}	0.09^{ns}
Ascorbic acid concentrations (AsA)	3	77.72^{ns}	61.31^{***}
Linear regression	1	753.62^{***}	0.75^{ns}
Quadratic regression	1	6.25^{ns}	98.15^{***}
Interaction (ECw × AsA)	12	67.47^{***}	13.79^{***}
Blocks	3	19.38^{ns}	0.14^{ns}
Residue	57	31.27	0.67
CV (%)		8.55	5.66

DF – degrees of freedom; CV – coefficient of variation; **, ***, ^{ns} – significant at $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

Regarding relative water content (Fig. 2A), a reduction of 12.64% was observed with the increase in the electrical conductivity of irrigation water from 0.3 to 4.3 dS m^{-1}, when AsA was not applied. On the other hand, when foliar application of 360 mg L^{-1} of ascorbic acid was combined with irrigation using ECw of 0.3 dS m^{-1}, the highest value (75.17%) was recorded, representing an increase of 4.54% compared with the control treatment. The concentration of 360 mg L^{-1} of AsA increased RWC even under irrigation with ECw of 4.3 dS m^{-1}, resulting in an increase of 4.54% compared with plants irrigated with the same salinity level but without the application of AsA.



X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively. ^{ns} – Not significant by the F test. Vertical bars represent the standard error of the mean (n = 4).

Fig. 2 Relative water content – RWC (A) and electrolyte leakage – EL (B) in sour passion fruit seedlings cv. BRS GA1 as a function of the interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations, at 70 days after sowing (DAS).

As ECw increased from 0.3 to 4.3 dS m^{-1}, electrolyte leakage in the leaf blade (Fig. 2B) of sour passion fruit cv. BRS GA1 increased by 4.92% when ascorbic acid was not applied. However, this effect was mitigated by the estimated concentration of 110 mg L^{-1} of AsA. The lowest EL value (10.95%) was observed in plants grown under ECw of 0.3 dS m^{-1} and treated with 110 mg L^{-1} of AsA, representing a reduction of 0.65% compared with the control treatment. A similar response was observed in plants irrigated with ECw of 4.3 dS m^{-1}, in which the application of ascorbic acid reduced EL by 0.65% compared with plants cultivated under the same salinity level but without AsA application. However, concentrations higher than this intensified the deleterious effects of irrigation water salinity, particularly under the highest salinity level. The highest EL value (19.52%) was observed in plants subjected to 360 mg L^{-1} of AsA.

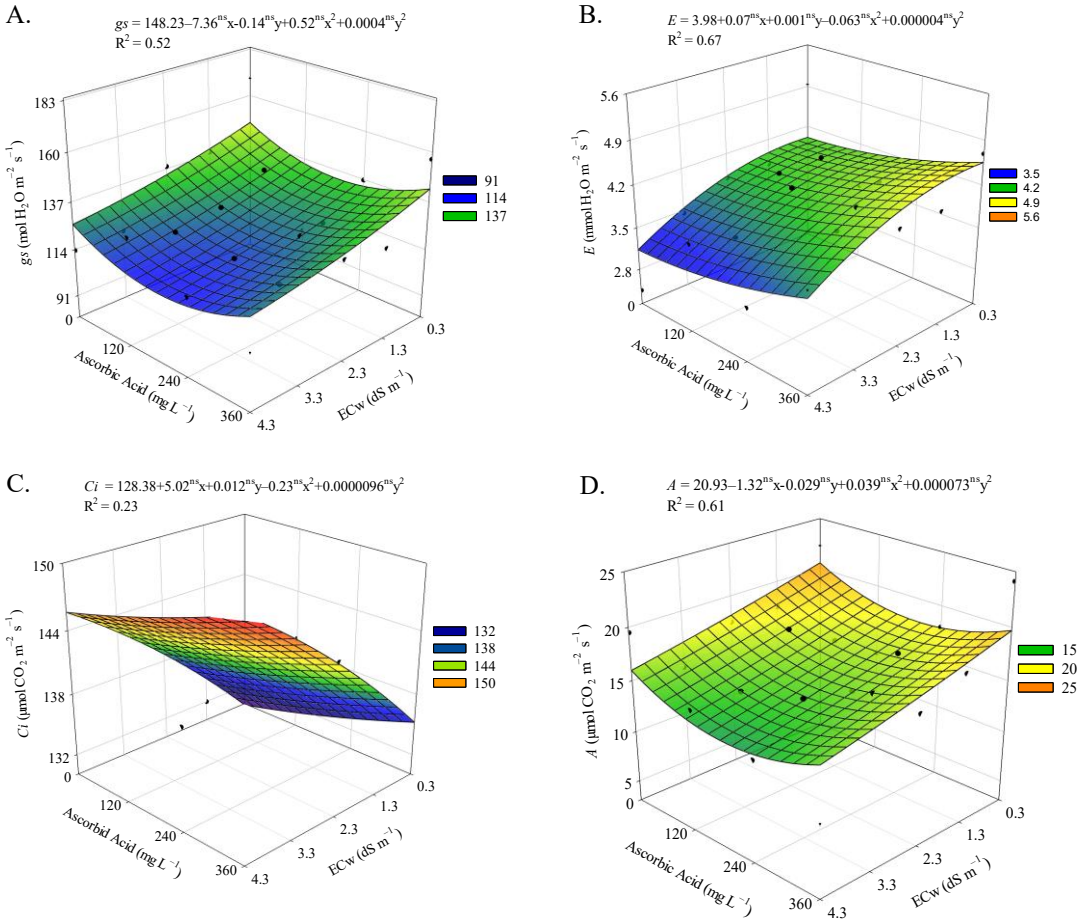
A significant interaction ($p \leq 0.001$) between irrigation water electrical conductivity and ascorbic acid concentrations (ECw × AsA) was observed for all analyzed variables (Table 2).

Table 2. Summary of the analysis of variance for stomatal conductance *(gs)*, transpiration (*E*), internal CO_2 concentration (*Ci*), and CO_2 assimilation rate (*A*) of sour passion fruit seedlings cv. BRS GA1 cultivated under different levels of irrigation water electrical conductivity and foliar application of ascorbic acid, at 70 days after sowing (DAS).

Source of variation	DF	Mean squares			
		gs	*E*	*Ci*	*A*
Eletrical conductivity of irrigation water (ECw)	4	1179.61***	2.66**	1873.11***	57.75***
Linear regression	1	737.31***	11.53***	25.60^{ns}	31.32***
Quadratic regression	1	396.44**	0.00^{ns}	3944.64**	83.05***
Ascorbic acid concentrations (AsA)	3	787.74***	1.22*	2440.35***	34.07***
Linear regression	1	0.20^{ns}	0.005^{ns}	1394.45***	19.01*
Quadratic regression	1	8.10***	4.20**	484.00***	238.70***
Interaction (ECw × AsA)	12	1341.96***	1.08***	3230.30***	40.20***
Blocks	3	1.84^{ns}	2.96^{ns}	9.40^{ns}	2.42^{ns}
Residue	57	33.51	0.32	12.95	2.10
CV (%)		4.51	14.36	2.56	8.68

DF – degrees of freedom; CV – coefficient of variation; *, **, ***, ^{ns} – significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

When plants that did not receive foliar application of ascorbic acid were evaluated, a 13.60% reduction in stomatal conductance (*gs*) was observed (Fig. 3A) as irrigation water electrical conductivity increased from the lowest to the highest level. The application of 360 mg L^{-1} of AsA in sour passion fruit cv. BRS GA1, irrigated with ECw of 0.3 dS m^{-1}, resulted in the highest gs value (147.51 mol H_2O m^{-2} s^{-1}), representing an increase of 1.00% (1.44 mol H_2O m^{-2} s^{-1}) compared with the control treatment. A similar response was observed in plants grown under the highest salinity level (4.3 dS m^{-1}), where the application of 360 mg L^{-1} of AsA increased gs by 1.13% (1.44 mol H_2O m^{-2} s^{-1}) compared with plants irrigated with the same ECw level but without ascorbic acid application, which showed the lowest value (126.19 mol H_2O m^{-2} s^{-1}).



X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively. ^{ns} – Not significant according to the F test. Vertical bars represent the standard error of the mean (n = 4).

Fig. 3 Stomatal conductance – *gs* (A), transpiration – *E* (B), internal carbon concentration – *Ci* (C), and CO_2 assimilation rate – *A* (D) of sour passion fruit seedlings cv. BRS GA1, as a function of the interaction between different levels of irrigation water electrical conductivity and ascorbic acid concentrations, at 70 days after sowing (DAS).

For transpiration (Fig. 3B), a reduction of 22.01% (0.87 mmol H_2O m^{-2} s^{-1}) was observed as irrigation water salinity increased from the lowest to the highest level in the absence of AsA. The application of 360 mg L^{-1} of ascorbic acid resulted in the highest value (4.54 mmol H_2O m^{-2} s^{-1}) when irrigation was performed with an estimated ECw of 0.5 dS m^{-1}, representing an increase of 13.47% in E compared with plants irrigated with the same irrigation water electrical conductivity but without the application of ascorbic acid. A beneficial effect of 360 mg L^{-1} of AsA was also observed in plants irrigated with high ECw (4.3 dS m^{-1}), resulting in an increase of 17.29% (0.54 mmol H_2O m^{-2} s^{-1}) compared with plants cultivated under the same irrigation conditions but treated with 0 mg L^{-1} of AsA.

For internal carbon concentration (Fig. 3C), an increase of 12.20% (15.85 µmol CO_2 m^{-2} s^{-1}) was observed as irrigation water salinity increased from 0.3 to 4.3 dS m^{-1}. An increase in Ci was also observed with the application of ascorbic acid. The maximum estimated value (151.26 µmol CO_2 m^{-2} s^{-1}) was recorded in plants that received foliar application of 360 mg L^{-1} of AsA and were irrigated with ECw of 4.3 dS m^{-1}, representing an increase of 3.81% (5.54 µmol CO_2 m^{-2} s^{-1}) compared with plants grown under the same ECw but without AsA application. The lowest value (129.86 µmol CO_2 m^{-2} s^{-1}) was observed in plants of the control treatment.

As ECw increased from 0.3 to 4.3 dS m^{-1}, a 22.21% reduction (4.56 µmol CO_2 m^{-2} s^{-1}) was observed for the CO_2 assimilation rate (Fig. 3D) when ascorbic acid was not applied. The control treatment showed the maximum value of 20.54 µmol CO_2 m^{-2} s^{-1} for A. However, a reduction in the CO_2 assimilation rate was observed with the application of AsA, with the lowest estimated value (13.09 µmol CO_2 m^{-2} s^{-1}) obtained with 200 mg L^{-1} of AsA under ECw of 4.3 dS m^{-1}, representing a decrease of 18.03% (2.88 µmol CO_2 m^{-2} s^{-1}) compared with plants irrigated with the same salinity level but without the application of AsA (0 mg L^{-1}).

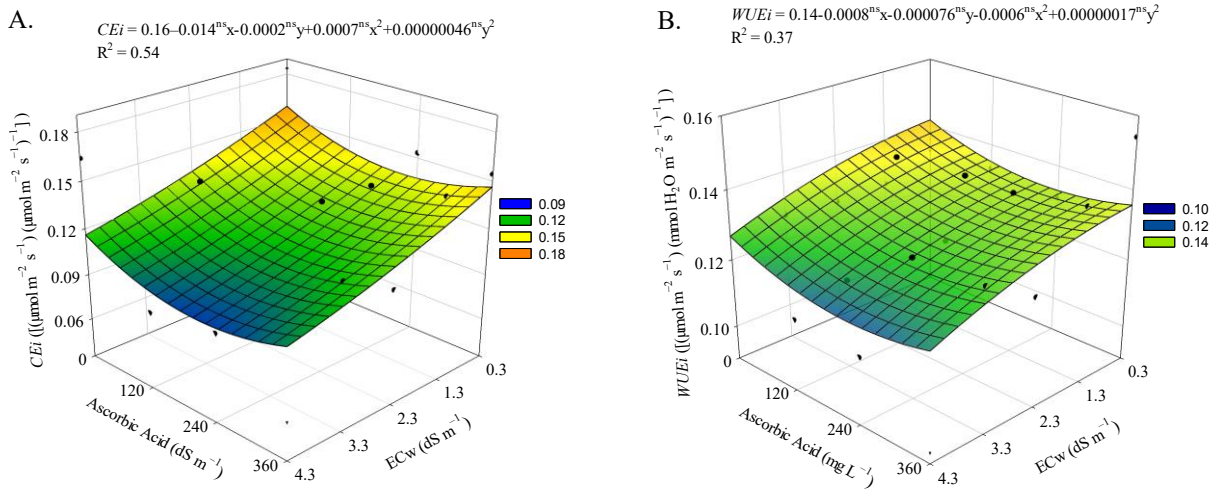
A significant interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations (ECw × AsA) was observed for instantaneous carboxylation efficiency (*CEi*) and instantaneous water use efficiency (*WUEi*) in sour passion fruit seedlings cv. BRS GA1 (Table 3).

Table 3. Summary of the analysis of variance for instantaneous carboxylation efficiency (*CEi*) and instantaneous water use efficiency (*WUEi*) of sour passion fruit seedlings cv. BRS GA1 cultivated under different levels of irrigation water electrical conductivity and foliar application of ascorbic acid, at 70 days after sowing (DAS).

Source of variation	DF	Mean squares	
		CEi	*WUEi*
Eletrical conductivity of irrigation water (ECw)	4	$5.40x10^{-3**}$	$7.16x10^{-3*}$
Linear regression	1	$1.53x10^{-2*}$	$2.50x10^{-2***}$
Quadratic regression	1	$1.72x10^{-2***}$	$3.83x10^{-2***}$
Ascorbic acid concentrations (AsA)	3	$3.85x10^{-3ns}$	$5.76x10^{-3*}$
Linear regression	1	$2.02x10^{-4ns}$	$8.01x10^{-5*}$
Quadratic regression	1	$8.21x10^{-3***}$	$2.01x10^{-5ns}$
Interaction (ECw × AsA)	12	$4.02x10^{-3*}$	$1.33x10^{-3***}$
Blocks	3	$8.13x10^{-5ns}$	$1.33x10^{-3ns}$
Residue	57	$1.27x10^{-4}$	$1.32x10^{-4}$
CV (%)		9.20	9.16

DF – degrees of freedom; CV – coefficient of variation; *, **, ***, ^{ns} – significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

For instantaneous carboxylation efficiency (Fig. 4A), a reduction of 27.30% (0.04 [(µmol m^{-2} s^{-1})(µmol m^{-2} s^{-1})$^{-1}$]) was observed as ECw increased from 0.3 to 4.3 dS m^{-1}. Plants subjected to an estimated concentration of 220 mg L^{-1} of AsA showed an intensification of the deleterious effects of saline irrigation, presenting the lowest value (0.093 [(µmol m^{-2} s^{-1})(µmol m^{-2} s^{-1})$^{-1}$]) under irrigation with the highest ECw level (4.3 dS m^{-1}). This value was 18.93% (0.021 [(µmol m^{-2} s^{-1})(µmol m^{-2} s^{-1})$^{-1}$]) lower than that observed in plants irrigated with the same electrical conductivity level but without AsA application.



X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively. ^{ns} – Not significant according to the F test. Vertical bars represent the standard error of the mean (n = 4).

Fig. 4 Instantaneous carboxylation efficiency – *CEi* (A) and instantaneous water use efficiency – *WUEi* (B) of sour passion fruit seedlings cv. BRS GA1, as affected by the interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations, at 70 days after sowing (DAS).

For instantaneous water use efficiency (Fig. 4B), a reduction of 10.19% (0.125 [(µmol m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$]) was observed as irrigation water salinity increased from the lowest to the highest level. Plants from the control treatment showed the highest estimated value (0.125 [(µmol m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$]) for *WUEi*. A reduction in *WUEi* was also observed in sour passion fruit seedlings cv. BRS GA1 as a function of ascorbic acid concentrations. The lowest estimated value (0.117 [(µmol m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$]) was recorded in plants subjected to an estimated concentration of 230 mg L^{-1} of AsA and irrigated with ECw of 4.3 dS m^{-1}, representing a reduction of 6.98% (0.08 [(µmol m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$]) compared with plants irrigated under the same salinity level but without AsA application.

A significant interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations (ECw × AsA) was observed for chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and total chlorophyll (Chl total) contents (Table 3).

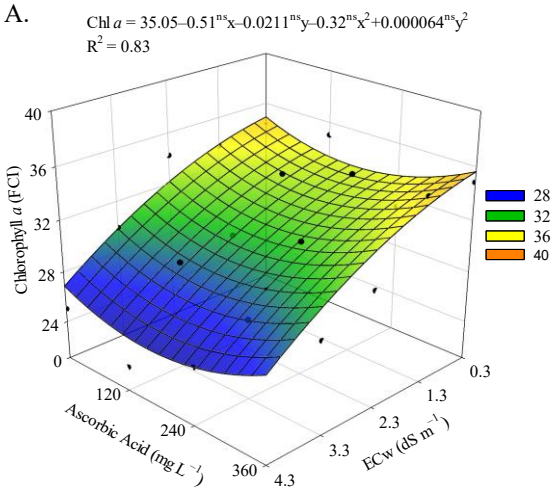
Table 3. Summary of the analysis of variance for chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and total chlorophyll (Chl total) contents of sour passion fruit seedlings cv. BRS GA1 cultivated under different levels of irrigation water electrical conductivity and foliar application of ascorbic acid, at 70 days after sowing (DAS).

Source of variation	DF	Mean squares		
		Chl *a*	Chl *b*	Chl total
Eletrical conductivity of irrigation water (ECw)	4	173.24***	10.29**	314.63***
Linear regression	1	206.11***	10.81***	609.96***
Quadratic regression	1	49.40**	0.18^{ns}	180.00**
Ascorbic acid concentrations (AsA)	3	25.34**	1.38*	30.10^{ns}
Linear regression	1	1.54^{ns}	6.67**	105.30*
Quadratic regression	1	10.10^{ns}	1.15^{ns}	87.25^{ns}
Interaction (ECw × AsA)	12	25.26**	1.37**	48.56*
Blocks	3	1.02^{ns}	0.28^{ns}	3.63^{ns}
Residue	57	3.64	0.31	12.78
CV (%)		6.16	8.27	9.56

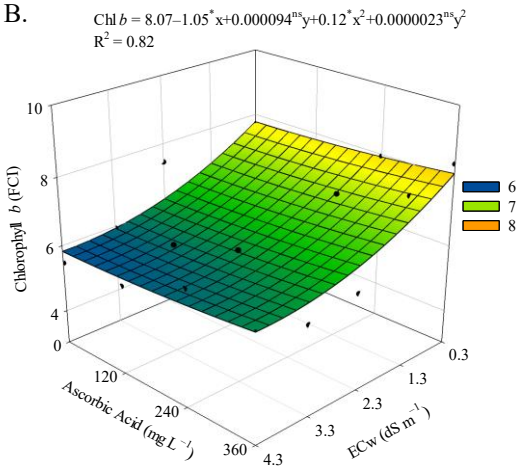
DF – degrees of freedom; CV – coefficient of variation; *, **, ***, ^{ns} – significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

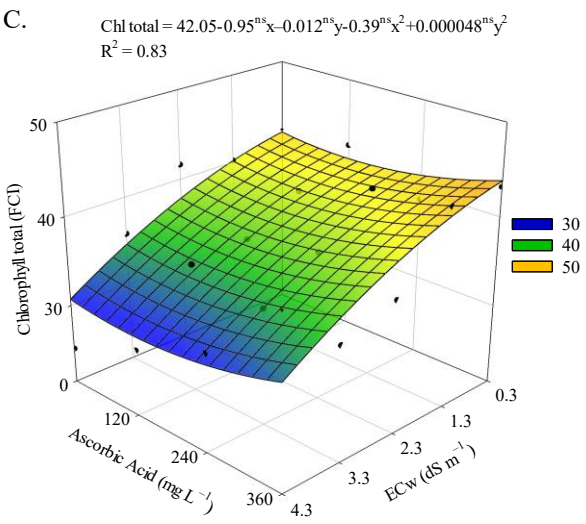
For chlorophyll *a* content (Fig. 5A), a reduction of 22.74% was observed as irrigation water salinity increased from 0.3 to 4.3 dS m^{-1}. However, a beneficial effect of ascorbic acid application was observed. The highest AsA concentration showed a positive effect in plants irrigated with ECw of 4.3 dS m^{-1}, resulting in an increase of 2.00% (0.68 FCI) compared with plants cultivated under the same irrigation conditions but without AsA application (0 mg L^{-1}). Nevertheless, the highest value (35.06 FCI) was observed in plants sprayed with 360 mg L^{-1} of AsA and irrigated with ECw of 0.3 dS m^{-1}, representing an increase of 2.53% (0.69 FCI) compared with the control treatment.

A.



B.





X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively; * and ^{ns} – Significant at $p \leq 0.05$ and not significant according to the F test, respectively. Vertical bars represent the standard error of the mean (n = 4).

Fig. 5 Chlorophyll *a* – Chl *a* (A), chlorophyll *b* – Chl *b* (B), and total chlorophyll – Chl total (C) of sour passion fruit seedlings cv. BRS GA1, as affected by the interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations, at 70 days after sowing (DAS).

In the absence of AsA, chlorophyll *b* content (Fig. 5B) decreased by 1.99 FCI as ECw increased from 0.3 to 4.3 dS m^{-1}. However, these effects were mitigated by the application of ascorbic acid. Plants treated with 360 mg L^{-1} of AsA and irrigated with ECw of 0.3 dS m^{-1} showed the highest value (8.1 FCI), which was 4.30% (0.32 FCI) higher than that observed in the control treatment. A similar response was observed in plants cultivated under ECw of 4.3 dS m^{-1}, in which the application of 360 mg L^{-1} of AsA increased Chl *b* content by 5.75% (0.33 FCI) compared with plants irrigated with the same electrical conductivity level but without AsA application (0 mg L^{-1}).

For total chlorophyll content (Fig. 5C), a reduction of 26.30% (26.30 FCI) was observed as irrigation water electrical conductivity increased from the lowest to the highest level. A similar response to that observed for Chl *a* (Fig. 5A) and Chl *b* (Fig. 5B) was also found for total chlorophyll, where the application of 360 mg L^{-1} of AsA combined with ECw of 0.3 dS m^{-1} resulted in the highest value (43.63 FCI), representing an increase of 4.56% (1.93 FCI) compared with the control treatment.

On the other hand, the lowest estimated value (30.75 FCI) was observed in plants that did not receive foliar application of ascorbic acid and were irrigated with the highest salinity level (4.3 dS m^{-1}). These effects were attenuated by the application of 360 mg L^{-1} of AsA, which increased total chlorophyll content by 6.18% (1.90 FCI) in plants irrigated with ECw of 4.3 dS m^{-1}.

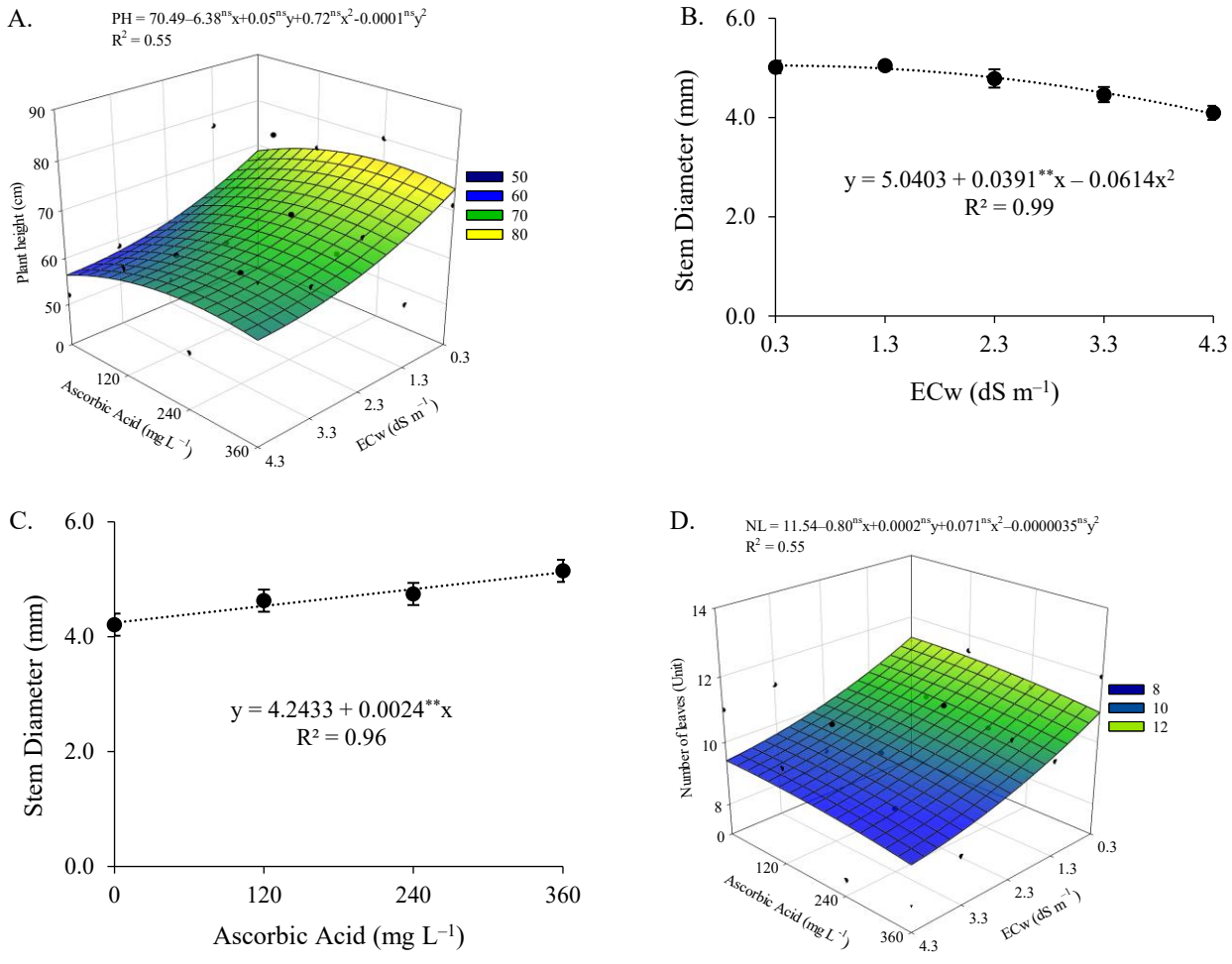
The analysed factors (ECw × AsA) significantly affected plant height and number of leaves (Table 4). Individually, irrigation water electrical conductivity levels and ascorbic acid concentrations were significant ($p \leq 0.01$) for stem diameter.

Table 4. Summary of the analysis of variance for plant height (PH), stem diameter (SD), and number of leaves (NL) of sour passion fruit seedlings cv. BRS GA1 cultivated under different irrigation water electrical conductivity levels and foliar application of ascorbic acid, at 67 days after sowing (DAS).

Source of variation	DF	Mean squares		
		PH	SD	NL
Eletrical conductivity of irrigation water (ECw)	4	419.90^{***}	2.61^{**}	11.85^{***}
Linear regression	1	1.00^{***}	9.48^{*}	1.60^{*}
Quadratic regression	1	30.02^{ns}	0.84^{***}	16.70^{***}
Ascorbic acid concentrations (AsA)	3	241.34^{**}	1.38^{**}	1.28^{*}
Linear regression	1	56.96^{*}	8.57^{**}	0.6^{ns}
Quadratic regression	1	236.10^{***}	0.001^{ns}	0.56^{ns}
Interaction (ECw × AsA)	12	386.03^{***}	0.30^{ns}	7.36^{***}
Blocks	3	3.85^{ns}	0.37^{ns}	0.38^{ns}
Residue	57	9.59	0.22	0.25
CV (%)		4.72	10.02	5.01

DF – degrees of freedom; CV – coefficient of variation; *, **, ***, ^{ns} – significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

As irrigation water salinity increased from 0.3 to 4.3 dS m^{-1}, plant height (Fig. 6A) was reduced by 17.88% (12.27 cm). However, this effect was mitigated by the application of ascorbic acid. Plants subjected to an estimated concentration of 250 mg L^{-1} of AsA and irrigated with ECw of 0.3 dS m^{-1} showed the highest plant height (74.90 cm), representing an increase of 6.25 cm compared with the control treatment. A beneficial effect of ascorbic acid was also observed in plants irrigated with the highest ECw level (4.3 dS m^{-1}), resulting in an increase of 11.09% (6.25 cm) compared with plants cultivated under the same irrigation conditions but without AsA application.



X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively; ** and ^{ns} – Significant at $p \leq 0.01$ and not significant according to the F test, respectively. Vertical bars represent the standard error of the mean (n = 4).

Fig. 6 Plant height – PH (A) and number of leaves – NL (C) of sour passion fruit seedlings cv. BRS GA1 as affected by the interaction between irrigation water electrical conductivity levels (ECw) and ascorbic acid concentrations (AsA), and stem diameter – SD (B) as a function of ECw levels and AsA concentrations, at 67 days after sowing (DAS).

As irrigation water salinity increased from 0.3 to 4.3 dS m^{-1}, stem diameter (Fig. 6B) of sour passion fruit seedlings cv. BRS GA1 decreased by 19.29%, corresponding to 0.97 mm. In contrast, stem diameter (Fig. 6C) increased linearly by 19.68% as ascorbic acid concentration increased from 0 to 360 mg L^{-1}, with an increment of 0.57% per unit of AsA.

The number of leaves (Fig. 6D) decreased by 20.14% (2.40 units) as irrigation water salinity increased from 0.3 to 4.3 dS m^{-1} when ascorbic acid was not applied. However, no substantial increases in NL were observed in sour passion fruit seedlings cv. BRS GA1 as a function of ascorbic acid concentrations, with the highest estimated value (11.78 leaves) observed in the control treatment. The application of 360 mg L^{-1} of AsA intensified the deleterious effects of salinity when combined with irrigation at ECw of 4.3 dS m^{-1}, resulting in a 4.05% reduction (0.38 leaves) compared with plants irrigated with the same electrical conductivity level but without AsA application.

The interaction between irrigation water salinity levels (ECw) and ascorbic acid concentrations (AsA) significantly affected all dry mass variables ($p \leq 0.01$), as shown in Table 5.

Table 5. Summary of the analysis of variance for leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), dry mass of the aerial part (DMAP), and total dry mass (TDM) of sour passion fruit seedlings cv. BRS GA1 cultivated under different irrigation water electrical conductivity levels and foliar application of ascorbic acid, at 70 days after sowing (DAS).

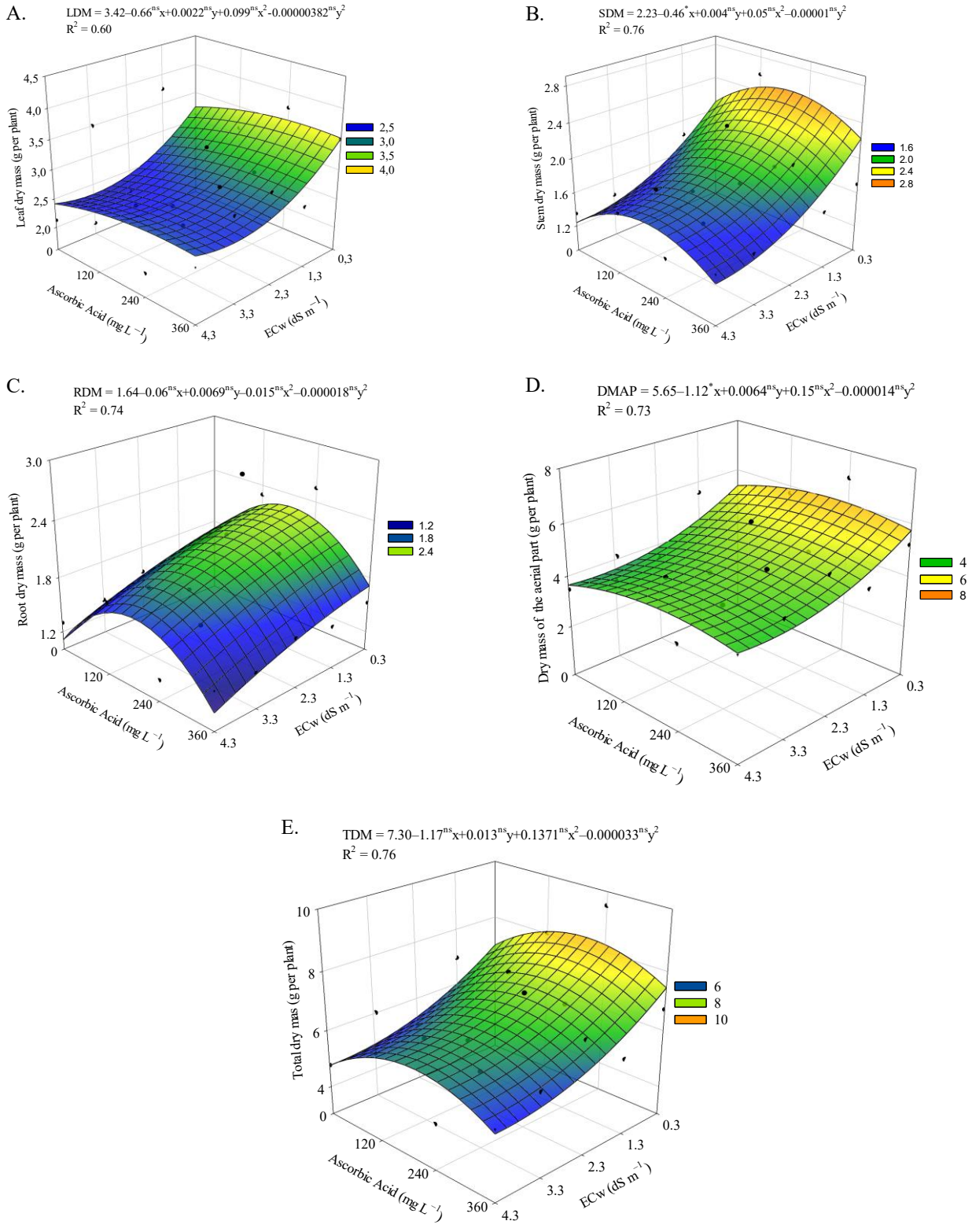
Source of variation	DF	Mean squares				
		LDM	SDM	RDM	DMAP	TDP
Eletrical conductivity of irrigation water (ECw)	4	2.35^{**}	2.06^{***}	0.86^{***}	8.35^{***}	13.29^{***}
Linear regression	1	6.24^{***}	0.87^{**}	3.72^{***}	11.77^{***}	13.92^{***}
Quadratic regression	1	0.14^{ns}	0.06^{ns}	1.08^{***}	0.30^{ns}	0.28^{ns}
Ascorbic acid concentrations (AsA)	3	0.62^{*}	0.70^{**}	1.99^{***}	6.69^{**}	6.94^{***}
Linear regression	1	2.45^{**}	0.031^{ns}	0.01^{ns}	0.70^{ns}	0.90^{ns}
Quadratic regression	1	0.18^{ns}	5.17^{***}	3.24^{***}	6.37^{**}	18.70^{***}
Interaction (ECw × AsA)	12	1.51^{***}	0.56^{***}	0.38^{***}	2.81^{***}	4.34^{***}
Blocks	3	0.37^{ns}	0.021^{ns}	0.052^{ns}	0.31^{ns}	0.37^{ns}
Residue	57	0.17	0.093	0.074	0.30	0.38
CV (%)		14.76	17.10	15.94	11.90	9.86

DF – degrees of freedom; CV – coefficient of variation; *, **, ***, ^{ns} – significant at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

Regarding leaf dry mass (Fig. 7A), an increase in irrigation water salinity from 0.3 to 4.3 dS m^{-1} resulted in a reduction of 25.33% (0.83 g per plant). However, these effects were mitigated by the application of ascorbic acid. Sour passion fruit seedlings cv. BRS GA1 subjected to an estimated concentration of 290 mg L^{-1} of AsA and irrigated with ECw of 0.3 dS m^{-1} showed the maximum value (3.55 g per plant) for LDM, which was 9.86% (0.33 g per plant) higher than that observed in the control

treatment. At the highest ECw level, a beneficial effect of AsA was also observed, where the concentration of 290 mg L^{-1} increased leaf dry mass by 13.20% (0.32 g per plant) compared with plants cultivated under the same irrigation water electrical conductivity but without AsA application (0 mg L^{-1}).

.



406 X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively; * and ^{ns} –
407 Significant at $p \leq 0.05$ and not significant according to the F test, respectively. Vertical bars represent the standard error
408 of the mean (n = 4).

409 **Fig. 7** Leaf dry mass – LDM (A), stem dry mass – SDM (B), root dry mass – RDM (C), dry mass of the
410 aerial part – DMAP (D), and total dry mass – TDM (E) of sour passion fruit seedlings cv. BRS GA1 as
411 affected by the interaction between irrigation water electrical conductivity levels (ECw) and ascorbic acid
412 concentrations (AsA), at 75 days after sowing (DAS).

413 Irrigation with ECw of 4.3 dS m^{-1} reduced stem dry mass (Fig. 7B) by 43.88% (0.92 g per plant)
414 compared with plants irrigated with the lowest salinity level. However, a beneficial effect of ascorbic acid
415 was observed. Plants subjected to an estimated concentration of 200 mg L^{-1} of AsA and irrigated with ECw
416 of 0.3 dS m^{-1} showed the highest value (2.50 g per plant) for SDM, representing an increase of 19.08%
417 (0.40 g per plant) compared with the control treatment. This concentration also promoted increases under
418 irrigation with ECw of 4.3 dS m^{-1}, raising SDM by 0.40 g per plant compared with plants irrigated with the
419 same electrical conductivity level but without AsA application (0 mg L^{-1}), which showed the lowest value
420 (1.17 g per plant).

421 Increasing ECw from 0.3 to 4.3 dS m^{-1} reduced root dry mass (Fig. 7C) by 31.84% (0.52 g per
422 plant). However, similarly to what was observed for stem dry mass, the application of ascorbic acid at the
423 estimated concentration of 200 mg L^{-1} increased RDM in sour passion fruit seedlings cv. BRS GA1. The
424 maximum value (2.28 g per plant) was observed in plants treated with 200 mg L^{-1} of AsA and irrigated with
425 ECw of 0.3 dS m^{-1}. The beneficial effect of foliar spraying with 200 mg L^{-1} of AsA was also observed in
426 plants cultivated under ECw of 4.3 dS m^{-1}, increasing RDM by 59.75% (0.66 g per plant) compared with
427 plants irrigated under the same conditions but without AsA application.

428 As ECw increased from 0.3 to 4.3 dS m^{-1}, shoot dry mass (Fig. 7D) decreased by 1.72 g per plant.
429 These effects were mitigated by the application of ascorbic acid, with an estimated concentration of 230
430 mg L^{-1}, which resulted in the highest value (6.06 g per plant) in plants irrigated with ECw of 0.3 dS m^{-1},
431 representing an increase of 13.07% (0.74 g per plant) compared with the control treatment. The effects of
432 this concentration were also observed in plants cultivated under ECw of 4.3 dS m^{-1}, increasing DMAP by
433 20.27% (0.73 g per plant) compared with plants irrigated under the same conditions but without AsA
434 application, which showed the lowest value (3.60 g per plant).

435 When evaluating sour passion fruit seedlings cv. BRS GA1 without AsA application, it was
436 observed that increasing salinity from 0.3 to 4.3 dS m^{-1} reduced total dry mass (Fig. 7E) by 31% (4.80 g
437 per plant). However, the estimated concentration of 230 mg L^{-1} of AsA mitigated these effects. When this
438 concentration was associated with plants cultivated under the lowest salinity level (0.3 dS m^{-1}), an increase
439 of 17.87% (1.25 g per plant) was observed compared with plants irrigated under the same conditions but
440 without AsA application. A similar effect was observed for plants irrigated with ECw of 4.3 dS m^{-1}, in
441 which TDM increased by 25.90% (1.24 g per plant) compared with plants under the same salinity level but
442 without AsA application, which showed the lowest value (4.80 g per plant).

443 A significant interaction ($p \leq 0.05$) between ECw and AsA concentrations was observed for the
444 root-to-shoot ratio (RSR) and Dickson Quality Index (DQI) of sour passion fruit seedlings cv. BRS GA1
445 (Table 6).

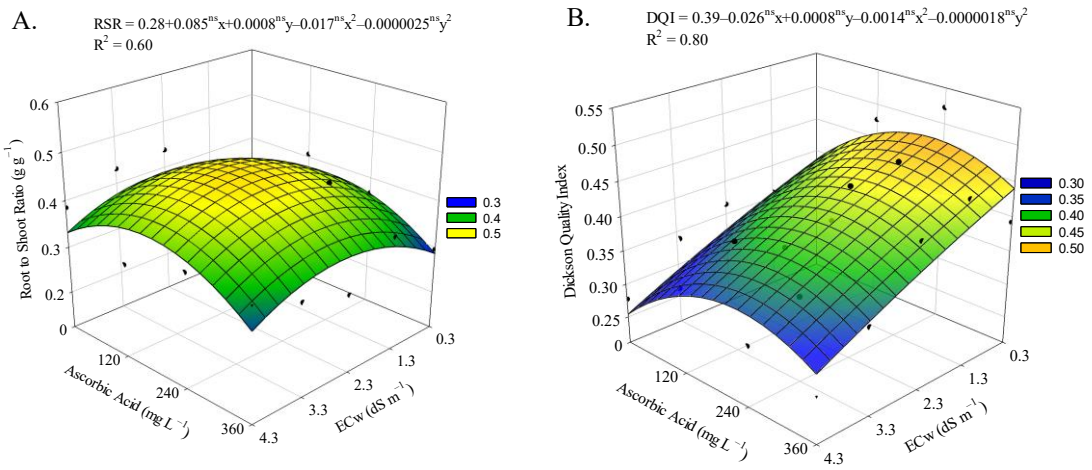
446

Table 6. Summary of the analysis of variance for root-to-shoot ratio (RSR) and Dickson Quality Index (DQI) of sour passion fruit seedlings cv. BRS GA1 cultivated under irrigation water salinity and foliar application of ascorbic acid, at 70 days after sowing (DAS).

Source of variation	DF	Mean squares	
		RSR	DQI
Eletrical conductivity of irrigation water (ECw)	4	$2.63x10^{-2**}$	$4.59x10^{-2***}$
Linear regression	1	$4.58x10^{-2**}$	$2.74x10^{-2***}$
Quadratic regression	1	$9.20x10^{-4ns}$	$1.62x10^{-3ns}$
Ascorbic acid concentrations (AsA)	3	$4.62x10^{-2**}$	$2.98x10^{-2***}$
Linear regression	1	$2.68x10^{-2ns}$	$3.92x10^{-3ns}$
Quadratic regression	1	$4.06x10^{-3ns}$	$6.18x10^{-3***}$
Interaction (ECw × AsA)	12	$2.04x10^{-2**}$	$1.12x10^{-3**}$
Blocks	3	$5.10x10^{-4ns}$	$2.42x10^{-5ns}$
Resíduo	57	0.27	$2.32x10^{-4}$
CV (%)		18.40	12.47

DF – degrees of freedom; CV – coefficient of variation; **, ***, ns – significant at $p \leq 0.01$, $p \leq 0.001$ and not significant, respectively.

The root-to-shoot ratio (Fig. 8A) increased by 27.07% (0.08 g g^{-1}) as ECw increased up to 2.5 dS m^{-1}, compared with plants irrigated with 0.3 dS m^{-1}. The highest estimated value (0.45 g g^{-1}) for RSR was observed in plants subjected to an estimated concentration of 160 mg L^{-1} of ascorbic acid under irrigation with ECw of 2.5 dS m^{-1}, representing an increase of 16.57% (0.064 g g^{-1}) compared with plants cultivated under the same irrigation conditions but without AsA application (0 mg L^{-1}). The lowest estimated value was observed in plants sprayed with 360 mg L^{-1} of AsA and irrigated with ECw of 0.3 dS m^{-1}, resulting in a reduction of 13.43% (0.036 g g^{-1}) compared with the control treatment.



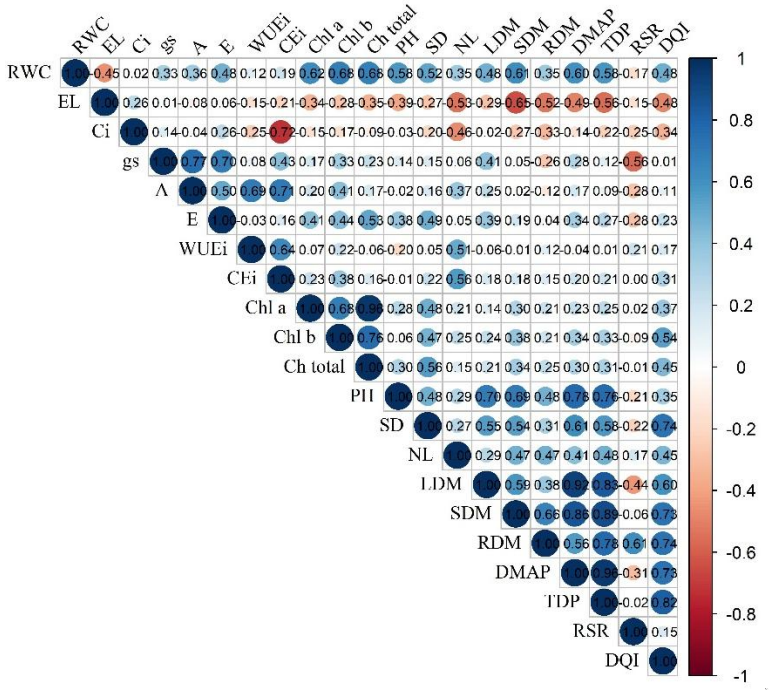
X and Y – Electrical conductivity of irrigation water and ascorbic acid concentrations, respectively. ns – Not significant according to the F test. Vertical bars represent the standard error of the mean (n = 4).

Fig. 8 Root-to-shoot ratio (RSR, A) and Dickson Quality Index (DQI, B) of sour passion fruit seedlings cv. BRS GA1 as affected by the interaction between irrigation water electrical conductivity levels (ECw) and ascorbic acid concentrations (AsA), at 75 days after sowing (DAS).

Increasing salinity from 0.3 to 4.3 dS m^{-1} reduced the Dickson Quality Index (Fig. 8B) by 33.96% (0.13). However, these effects were mitigated by the application of ascorbic acid. Plants treated with an estimated concentration of 220 mg L^{-1} of AsA and irrigated with ECw of 0.3 dS m^{-1} showed the highest

value (0.47), representing an increase of 23.26% (0.090) compared with the control treatment. Similarly, AsA at 220 mg L^{-1} attenuated the effects of irrigation with brackish water (ECw of 4.3 dS m^{-1}), resulting in an increase of 35.23% (0.089) compared with plants irrigated under the same conditions but without AsA application (0 mg L^{-1}).

Correlations were observed among all evaluated variables (Fig. 9); however, a greater number of significant correlations was found for variables related to plant growth, biomass accumulation, and seedling quality of sour passion fruit cv. BRS GA1. A strong positive correlation ($r \geq 0.60$) was observed between relative water content and photosynthetic pigment contents, as well as with growth variables, except for number of leaves and root dry mass.



Relative water content (RWC), electrolyte leakage (EL), stomatal conductance *(gs)*, transpiration (*E*), internal CO_2 concentration (*Ci*), CO_2 assimilation rate (*A*), instantaneous carboxylation efficiency (*CEi*) instantaneous water use efficiency (*WUEi*), chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl total), plant height (PH), stem diameter (SD), number of leaves (NL), leaf dry mass (LDM), stem dry mass (SDM), root dry mass (RDM), dry mass of the aerial part (DMAP), total dry mass (TDM) root-to-shoot ratio (RSR) and Dickson Quality Index (DQI)

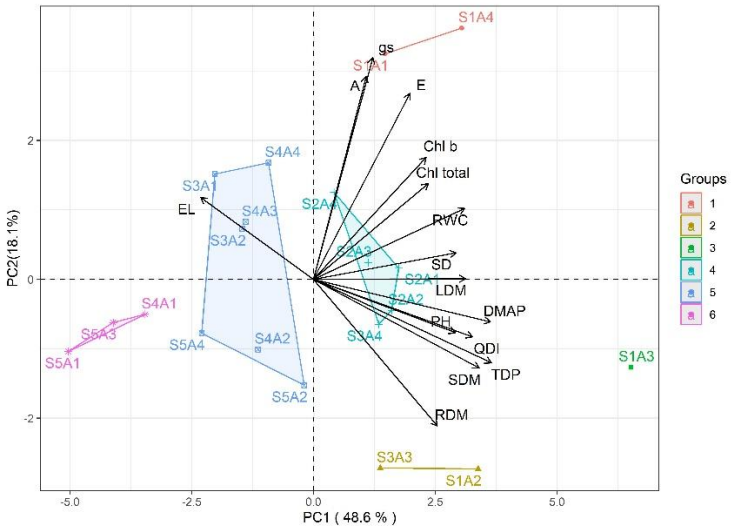
Fig. 9 Pearson correlation matrix as a function of the interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations in sour passion fruit cv. BRS GA1.

Electrolyte leakage showed a negative correlation with most variables, except for internal carbon concentration. However, EL showed $r \leq -0.50$ for number of leaves, stem dry mass, root dry mass, and total dry mass. Internal carbon concentration showed a strong negative correlation only with instantaneous carboxylation efficiency (−0.72) and a weak correlation (−0.46) with number of leaves. Stomatal conductance showed a strong positive correlation ($r \geq 0.60$) with CO_2 assimilation rate and transpiration, while a moderate negative correlation was observed with the root-to-shoot ratio (−0.56). Instantaneous carboxylation efficiency and instantaneous water use efficiency showed a strong positive correlation (0.60) with *A*, while a moderate correlation was observed with *E*.

Photosynthetic pigments showed moderate to strong correlations among themselves ($r \geq 0.50$), and a moderate correlation ($0.4 \leq r \leq 0.6$) was observed with stem diameter and the Dickson Quality Index. Growth variables showed a high correlation with biomass accumulation and seedling quality variables, with

strong positive correlations ($r \geq 0.60$) observed between plant height, leaf dry mass, stem dry mass, shoot dry mass, and total dry mass.

According to the principal component analysis (Fig. 10) of the variables as a function of the interaction between irrigation water electrical conductivity levels and ascorbic acid concentrations, the components explained 66.7% of the total variance of the dataset. PC1 alone explained 48.6%, showing positive correlations for RWC (0.78), Chl b (0.63), Chl t (0.63), PH (0.68), SD (0.73), LDM (0.74), SDM (0.83), RDM (0.62), DMAP (0.88), TDM (0.88), and DQI (0.82), forming groups 2 (S1A2 and S3A3), 3 (S1A3), and 4 (S2A1, S2A2, S2A3, S2A4, and S3A1).



S1A1 (0.3 dS m^{-1} e 0 mg L^{-1}); S1A2 (0.3 dS m^{-1} e 120 mg^{-1}); S1A3 (0.3 dS m^{-1} e 240 mg L^{-1}); S1A4 (0.3 dS m^{-1} e 360 mg L^{-1}); S2A1 (1.3 dS m^{-1} e 0 mg L^{-1}); S2A2 (1.3 dS m^{-1} e 120 mg L^{-1}); S2A3 (1.3 dS m^{-1} e 240 mg L^{-1}); S2A4 (1.3 dS m^{-1} e 360 mg L^{-1}); S3A1 (2.3 dS m^{-1} e 0 mg L^{-1}); S3A2 (2.3 dS m^{-1} e 120 mg L^{-1}); S3A3 (2.3 dS m^{-1} e 240 mg L^{-1}); S3A4 (2.3 dS m^{-1} e 360 mg L^{-1}); S4A1 (3.3 dS m^{-1} e 0 mg L^{-1}); S4A2 (3.3 dS m^{-1} e 120 mg L^{-1}); S4A3 (3.3 dS m^{-1} e 240 mg L^{-1}) e S4A4 (3.3 dS m^{-1} e 360 mg L^{-1}); S5A1 (4.3 dS m^{-1} e 0 mg L^{-1}); S5A2 (4.3 dS m^{-1} e 120 mg L^{-1}); S5A3 (4.3 dS m^{-1} e 240 mg L^{-1}) e S5A4 (4.3 dS m^{-1} e 360 mg L^{-1}).

Fig. 10 Two-dimensional projection of the principal component scores for irrigation water electrical conductivity levels (ECw), ascorbic acid concentrations (AsA), and the analyzed variables of sour passion fruit plants on the first two principal components (PC1 and PC2).

A negative correlation was observed only for electrolyte leakage (EL) (−0.61), which was associated with groups 6 (S4A1, S5A1, and S5A3) and 5 (S3A1, S3A2, S4A2, S3A3, and S4A4). The second principal component (PC2) explained 18.1% of the experimental variance and consisted only of negative correlations for stomatal conductance (*gs*) (−0.80), CO_2 assimilation rate (*A*) (−0.72), and transpiration (*E*) (−0.61). This component was represented exclusively by group 1, which included the treatments S1A1 and S1A4.

This behavior can be explained by the gas exchange responses of sour passion fruit seedlings cv. BRS GA1. The control treatment under the lowest salinity level (S1A1) showed the highest values for CO_2 assimilation rate (Fig. 9D). However, the highest stomatal conductance (Fig. 9A) was recorded in plants irrigated with the lowest salinity level and subjected to the application of 360 mg L^{-1} of ascorbic acid (S1A4), which favoured an increase in transpiration (Fig. 9E).

According to the plateau model (Fig. 11) as a function of irrigation water electrical conductivity levels, sour passion fruit cv. BRS GA1 showed a salinity threshold of 0.75 dS m^{-1}. A reduction of 8.97% per unit increase in ECw was observed.

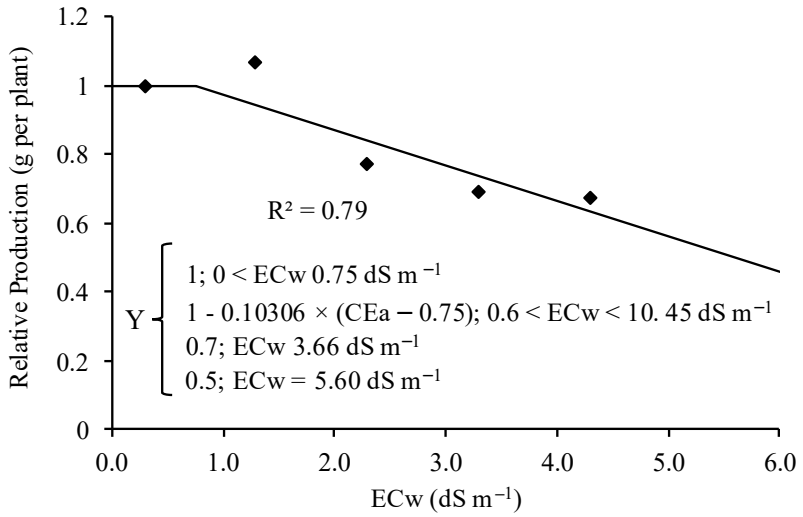


Fig. 11 Relative production of sour passion fruit cv. BRS GA1 as a function of irrigation water electrical conductivity (ECw), described by the plateau model.

Irrigation with ECw of 3.66 dS m^{-1} resulted in 70% relative production of sour passion fruit seedlings. In contrast, plants irrigated with ECw of 5.60 dS m^{-1} showed only 50% of the relative production.

4 Discussion

The global population is projected to reach nearly 10 billion people by 2050, and this growth will exert strong pressure on global agri-food systems (Zulfiqar and Ashraf 2021). However, climate change has altered precipitation patterns over time and space and increased global average temperatures, intensifying soil salinization processes (Adhikary et al. 2022). Currently, salinity affects about one-third of the world's arable land (Jamei et al. 2026), representing one of the main constraints to agricultural production, particularly in arid and semi-arid regions.

In recent decades, significant advances in agricultural technology have promoted innovations capable of increasing crop productivity and plant tolerance to environmental stresses (Jamei et al. 2026). In this context, there has been growing interest in strategies capable of mitigating the deleterious effects of salt stress in semi-arid regions, such as the foliar application of elicitors that induce stress tolerance in plants (Fátima et al. 2025). Among these substances, ascorbic acid (AsA), a non-enzymatic antioxidant compound, has emerged as a promising alternative for attenuating the effects of salt stress (Silva et al. 2025a).

In the present study, reductions in relative water content (RWC) were observed in sour passion fruit seedlings cv. BRS GA1. This result may be associated with the increase in salt concentration in the soil solution resulting from irrigation with brackish water. Excess salts reduce the soil osmotic potential, compromising water absorption by roots and consequently affecting plant water status, which results in lower relative water content (Liu et al. 2024).

However, these effects were mitigated by the application of ascorbic acid in sour passion fruit seedlings cv. BRS GA1, even at the highest irrigation water electrical conductivity level. This effect may be associated with the role of AsA in the antioxidant system and cellular redox balance, contributing to the maintenance of membrane integrity and, consequently, greater efficiency in water retention in plant tissues (El-Beltagi et al. 2022), thereby favoring greater turgor even under saline stress conditions. Exogenous application of AsA may enhance plant resistance to abiotic stress by strengthening the antioxidant system and modulating metabolic processes mediated by signaling molecules (Eskandarpour et al. 2025).

When irrigation was performed with brackish water, an increase in electrolyte leakage (EL) was observed in sour passion fruit seedlings. This increase is possibly associated with the reductions observed in relative water content (Fig. 2A). As cellular turgor is compromised, cells become more flaccid and susceptible to structural damage, particularly in membrane integrity. Under these conditions, salt stress intensifies the production of reactive oxygen species (ROS), promoting lipid peroxidation and increasing ion leakage (Souza et al. 2026), which contributes to higher electrolyte leakage. This behavior reinforces the negative correlation observed between these variables in the Pearson correlation matrix (Fig. 9) and in the principal component analysis (Fig. 10), where the groups associated with the highest EL values correspond to treatments with higher irrigation water salinity levels.

However, these effects were mitigated by the application of ascorbic acid, since AsA acts as a non-enzymatic antioxidant, reducing oxidative stress induced by salt stress through the neutralization of excess ROS, thereby preserving membrane integrity (Saleem et al. 2025) and preventing electrolyte leakage. Similar trends were observed by Torres et al. (2025) when evaluating the effects of ascorbic acid on the morphophysiology of guava plants irrigated with brackish water. In that study, concentrations of 30, 60, and 90 mM reduced electrolyte leakage by 13.72%, 14.57%, and 13.62%, respectively, in plants irrigated with ECw levels of 1.8, 2.0, and 1.7 dS m^{-1}.

Reductions in stomatal conductance (*gs*) and transpiration (*E*) were observed in sour passion fruit seedlings cv. BRS GA1. Under salt stress conditions, these responses are generally associated with an adaptive mechanism, in which stomatal closure occurs in order to reduce excessive water loss through transpiration (Souza et al. 2026). Moreover, this process is frequently mediated by increased levels of the hormone abscisic acid (ABA), which acts as an important physiological signalling molecule under stress conditions, promoting stomatal closure and contributing to the maintenance of plant water potential (Wu et al. 2025).

Nevertheless, a positive effect of AsA application on *gs* and *E* was observed. The beneficial effect of ascorbic acid may be mainly associated with osmotic adjustment, since it has been described as a molecule involved in abiotic stress signalling, modulating physiological responses related to osmotic adaptation and the preservation of cellular turgor (Ajila-Celi et al. 2025), which may favor the maintenance of stomatal opening. Consequently, greater stomatal opening (Fig. 3A) leads to higher transpiration rates (Fig. 3B), since these mechanisms are directly related, as observed in the correlation matrix (Fig. 9).

This increase in transpiration may also be associated with higher plant water content, which favours continuous water flow between the plant and the environment. Similar results were reported by Fatima et al. (2025), who demonstrated that this behavior may be related to a reduction in the synthesis or

signalling of abscisic acid, caused by the application of ascorbic acid, thereby allowing greater stomatal conductance and maintenance of transpiration.

Salt stress promotes partial stomatal closure, reducing the diffusion of CO_2 from the atmosphere into the leaf mesophyll (Saleem et al. 2025). However, the increase in internal CO_2 concentration (Ci) observed with increasing irrigation water electrical conductivity suggests that this limitation may not have been caused exclusively by stomatal factors. This accumulation of CO_2 may be attributed to a reduction in the carboxylation efficiency of the enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), compromising carbon fixation and favouring its oxygenase activity, thereby intensifying photorespiration (Fátima et al. 2025).

The reduction in CO_2 assimilation rate (*A*) corroborates the results observed for Ci, indicating a possible photorespiratory process, which reduces the plant's capacity to produce photo assimilates under saline conditions. During photorespiration, oxygen competes with CO_2 for the active site of RuBisCO, promoting the oxygenation of ribulose-1,5-bisphosphate and resulting in the formation of 2-phosphoglycolate and 3-phosphoglycerate (Fatima et al. 2025). The metabolism of 2-phosphoglycolate involves the integrated action of chloroplasts, peroxisomes, and mitochondria, resulting in high energy expenditure and the release of CO_2, ultimately reducing photosynthetic efficiency (Chen et al. 2025).

The increase in *Ci* combined with the reduction in *A* resulted in a decrease in instantaneous carboxylation efficiency (*CEi*) in sour passion fruit seedlings cv. BRS GA1, indicating inhibition of RuBisCO carboxylation activity even with partially open stomata. Salt stress causes damage to membrane permeability and stability due to ROS accumulation (Zhou et al. 2024), which compromises the photosynthetic apparatus and reduces photosynthetic efficiency (Torres et al. 2025).

Additionally, the gas exchange responses observed in this study may also be related to climatic conditions of the semi-arid region. Mou et al. (2025) reported that the optimal temperature for passion fruit growth ranges between 25 and 28 °C, whereas temperatures during the experiment reached up to 35 °C. According to Ghani et al. (2023), thermal stress in semi-arid regions intensifies photooxidative activity and physiological drought, leading to morphophysiological disturbances and increased ROS production.

The reduction in chlorophyll content under saline conditions may be associated with chloroplast degradation or increased activity of the enzyme chlorophyllase, promoting chlorophyll photooxidation and reducing antenna complex efficiency (Nedjimi et al. 2024). Under saline environments, reductions in the activity of photosystems I and II may occur, limiting electron transport and reducing photosynthetic efficiency (Sun et al. 2023). However, these effects were mitigated by the application of ascorbic acid, which can reduce the deleterious effects of salt stress by limiting ROS accumulation and protecting photosynthetic structures (Nawaz et al. 2021). In addition, AsA application increased plant water status, which may reduce ion leakage and oxidative damage to the antenna complex.

These results highlight the role of ascorbic acid in strengthening the antioxidant system, acting as a substrate for enzymes involved in the detoxification of H_2O_2 and singlet oxygen (O_2) (Foyer and Kunert 2024). Consequently, AsA helps maintain the structural integrity of chloroplasts and supports the energy supply required for the Calvin cycle (Wu et al. 2024).

Growth of sour passion fruit seedlings cv. BRS GA1 was negatively affected by irrigation with brackish water. Excess Na^+ ions reduce the absorption of K^+ and other nutrients, causing cytosolic nutrient

imbalance and impairing nutrient transport to the shoot, which compromises cell differentiation and plant growth (Brito et al. 2020; Silva et al. 2020).

Reductions in the number of leaves limit the photosynthetically active area, contributing to reductions in stomatal conductance and CO_2 assimilation rate, ultimately reducing the production of photo assimilates required for seedling growth. However, these effects were mitigated by the application of ascorbic acid, even under the highest ECw level. This response may be associated with improved cellular water status, which promotes cellular turgor and stimulates cell expansion and division. Similar results were reported by Silva et al. (2025b) in guava seedlings under saline stress.

Overall, salt accumulation in the soil solution inhibits plant growth due to increased metabolic energy demand, reduced carbon assimilation, and decreased photosynthetic efficiency (Lanza et al. 2021). Nevertheless, foliar application of AsA increased biomass accumulation, likely due to improved leaf area development, photosynthetic pigment content, and nutrient absorption (Saritha et al. 2017; Silva Júnior et al. 2021).

An increase in the root-to-shoot ratio was also observed, suggesting a plant acclimation strategy to saline stress, in which root growth is favoured to improve water uptake (Santos et al. 2020). Finally, according to the Maas and Hoffman (1977) model, sour passion fruit cv. BRS GA1 can be classified as sensitive to irrigation water salinity, which corroborates the results reported by Santos et al. (2024).

5 Conclusion

Electrical conductivity of irrigation water up to 4.3 dS m^{-1} inhibits plant growth, gas exchange, photosynthetic pigments, and biomass accumulation, while also increasing electrolyte leakage in the leaf blade of sour passion fruit seedlings. Foliar application of ascorbic acid at concentrations between 240 and 300 mg L^{-1} favours the maintenance of plant water status, cellular integrity, and seedling growth, even under higher irrigation water salinity. Ascorbic acid stimulates plant growth, leaf dry mass accumulation, and the Dickson Quality Index of sour passion fruit cv. BRS GA1. Sour passion fruit cv. BRS GA1 is sensitive to irrigation water salinity, presenting a threshold salinity level of 0.75 dS m^{-1}.

Acknowledgements Would like to thank the MASP Research Group and all its members for their technical support, scientific contributions, and ongoing collaboration throughout the development of this work.

Author Contributions GSdL, LAdAS and ERIdS; methodology, GSdL, ARdS and ERIdS; software, VMBdS, LDAB and JSN; validation, GSdL, LAdAS, RTdF and SSdS; formal analysis, ARdS and CAMS; investigation, ERIdS, FSdA, RTdF, VMBdS and LDAB; resources, GSdL, LAdAS and SSdS; data curation, ERIdS, LDAB and VFdOS; writing—original draft preparation, ARdS, ERIdS, GSdL and CAMS; writing—review and editing, GSdL, LAdAS and SSdS; visualization, VMBdS, LDAB and ERIdS; supervision, GSdL and LAdAS; project administration, GSdL and LAdAS; funding acquisition, GSdL and LAdAS. All authors have read and agreed to the published version of the manuscript.

Funding The Article Processing Charge for the publication of this research was funded by the Coordenacao de Aperfeicoamento de Pessoal de Nivel Superior (CAPES, Brazil).

Data availability Statement The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

669 **Conflicts of Interest** The authors declare no conflicts of interest.

670

671 **References**

672

673 Adhikary, S, Biswas, B, Chakraborty, D, Timsina, J, Pal, S, Tarafdar, JC, Banerje S, Hossain A, Roy S
674 (2022) Seed priming with selenium and zinc nanoparticles modifies germination, growth, and yield
675 of direct-seeded rice (*Oryza sativa* L.). Scientific reports, 12:7103. https://doi.org/10.1038/s41598-
676 022-11307-4

677 Ajila-Celi GE, Lata-Tenesaca LF, Calzada KP, Alves RC, Cruz MCP, Pinzetta Jr JS, Carrega WS, Gratão
678 PL (2025) Exogenous ascorbic acid mitigates salt-induced damage in soybean by modulating
679 photosynthesis, antioxidant defense, and ionic homeostasis. Acta Physiologiae Plantarum, 47.
680 https://doi.org/10.1007/s11738-025-03770-z

681 Akram NA, Shafiq F, Ashraf M (2017) Ascorbic acid a potential oxidant scavenger and its role in plant
682 development and abiotic stress tolerance. Frontiers in Plant Science, 8:613.
683 https://doi.org/10.3389/fpls.2017.00613

684 Alayafi AAM (2020) Exogenous ascorbic acid induces systemic heat stress tolerance in tomato seedlings:
685 transcriptional regulation mechanism. Environmental Science and Pollution Research, 27:19186-
686 19199. https://doi.org/10.1007/s11356-019-06195-7

687 Andrade JA, Nunes MA (2017) Acesso à água no Semiárido Brasileiro: uma análise das políticas públicas
688 implementadas na região. Revista Espinhaço, 3:28-39.

689 Arif Y, Singh P, Siddiqui H, Bajguz A, Hayat S (2020) Salinity induced physiological and biochemical
690 changes in plants: An omic approach towards salt stress tolerance. Plant Physiology and Biochemistry,
691 156:64-77. https://doi.org/10.1016/j.plaphy.2020.08.042

692 Bernardo S, Mantovani EC, Silva DD, Soares AA (2009) Manual de irrigação UFV.

693 Billah M, Rohman MM, Hossain N, Uddin MS (2017) Exogenous ascorbic acid improved tolerance in
694 maize (*Zea mays* L.) by increasing antioxidant activity under salinity stress. African Journal of
695 Agricultural Research, 12:1437-1446. https://doi.org/10.5897/AJAR2017

696 Bione MAA, Soares TM, Cova AMW, Paz VPS, Gheyi HR, Rafael MRS, Modesto FJN, Santana JA, Neves
697 BSL (2021) Hydroponic production of 'Biquinho' pepper with brackish water. Agricultural Water
698 Management, 245:1-10. https://doi.org/10.1016/j.agwat.2020.106607

699 Brito FAL, Thaline MP, Juliane M, Henschel SCV, Martins AZ, Dimas MR (2020) Elevated CO_2 improves
700 assimilation rate and growth of tomato plants under progressively higher soil salinity by decreasing
701 abscisic acid and ethylene levels. Environmental and Experimental Botany, 176:104050.
702 https://doi.org/10.1016/j.envexpbot.2020.104050

703 Celi GEA, Gratão PL, Lanza MGDB, Reis AR (2023) Physiological and biochemical roles of ascorbic acid
704 on mitigation of abiotic stresses in plants. Plant Physiology and Biochemistry, 202:107970.
705 https://doi.org/10.1016/j.plaphy.2023.107970

706 Chen J, Yan Y, Chen S, Ahammed GJ (2025) Photorespiration and plant immunity: interactions and
707 implications in a changing climate. Plant Physiology and Biochemistry, 229:110569.
708 https://doi.org/10.1016/j.plaphy.2025.110569

709 Dickson A, Leaf AL, Hosner JF (1960) Quality appraisal of white spruce and white pine seedling stock in

710 nurseries. The Forest Chronicle, 36:10-13. https://doi.org/10.5558/tfc36010-1
711 El-Beltagi HS, Ahmad I, Basit A, Shehata WF, Hassan U, Shah ST, Haleema B, Jalal A, Amin R, Khalid
712 MA, Noor F, Mohamed HI (2022) Ascorbic acid enhances growth and yield of sweet peppers
713 (*Capsicum annum*) by mitigating salinity stress. Gesunde Pflanzen, 74:423-433.
714 https://doi.org/10.1007/s10343-021-00619-6
715 Embrapa. BRS Sol do Cerrado: Híbrido de Maracujazeiro azedo para mesa e indústria. 2 ed. Brasília, DF:
716 Embrapa Cerrado, 2008. 2p.
717 Eskandarpour S, Einali A, Valizadeh J, Bahador E (2025) Ascorbic acid-induced metabolic responses and
718 antioxidant enzyme activity in the green microalga *Dunaliella salina* under long-term salinity. Aquac
719 Int 33:194. https://doi.org/10.1007/s10499-025-01865-5
720 Fatima RT, Lima GS, Soares LAA, Oliveira SVKN, Guedes MA, Ferreira JTA, Nóbrega JS, Gheyi HR,
721 Souto AGL, Pereira WE (2025). Effect of different timing of water deficit combined with foliar
722 application of ascorbic acid on physiological variables of sour passion fruit. Arid Land Research and
723 Management, 39:237-261. https://doi.org/10.1080/15324982.2024.2387098
724 Foyer CH, Kunert K (2024) The ascorbate–glutathione cycle coming of age. Journal of Experimental
725 Botany, 75:2682-2699. https://doi.org/10.1093/jxb/erae023
726 Ghani A, Yousaf MI, Hussain K, Hussain S, Razaq A, Akhtar N, Ibrar I, Kamal N, Ali B, Khan A, Shah S,
727 Khanum S, Hassan RM (2023) Relationship between high-temperature stress and key physio-
728 chemical, reactive oxygen species and antioxidants in spring maize hybrids under semi-arid
729 conditions. Biological and Clinical Sciences Research Journal, 2023:199.
730 https://doi.org/10.54112/bcsrj.v2023i1.199
731 Henschel JM, Soares VS, Figueiredo MC, Santos SK, Dias TJ, Batista DS (2023) Radish (*Raphanus sativus*
732 L.) growth and gas exchange responses to exogenous ascorbic acid and irrigation levels. Vegetos,
733 36:566-574. https://doi.org/10.1007/s42535-022-00422-2
734 Horchani F, Bouallegue A, Namsi A, Abbes Z (2024) Simultaneous Application of ascorbic acid and
735 Proline as a smart approach to mitigate the adverse effects of salt stress in wheat (*Triticum*
736 *aestivum*). Biology Bulletin, 51:1346-1363. https://doi.org/10.1134/S1062359024607171
737 IBGE - Instituto Brasileiro de Geografia e Estatística. Produção de Maracujá 2024 - Brasil. Disponível em:
738 https://www.ibge.gov.br/explica/producao-agropecuaria/maracuja/br.
739 Ikram M, Khalid B, Batool M, Ullah M, Zitong J, Rauf A, Wang B (2025) Secondary metabolites as
740 biostimulants in salt stressed plants: mechanisms of oxidative defense and signal transduction. Plant
741 Stress, 16:100891. https://doi.org/10.1016/j.stress.2025.100891
742 Iqbal W, Afridi MZ, Jamal A, Mihoub A, Saeed MF, Székely Á, Pompelli MF (2022) Canola seed priming
743 and its effect on gas exchange, chlorophyll photobleaching, and enzymatic activities in response to
744 salt stress. Sustainability, 14:9377. https://doi.org/10.3390/su14159377
745 Jamei R, Onsori O, Jamei M (2026) Nanoparticles and Salinity Stress: Emerging Insights into Plant
746 Responses and Stress Mitigation. Plant Stress, 20:101265.
747 https://doi.org/10.1016/j.stress.2026.101265
748 Karimi MR, Sabokdast M, Korang BH, Abbasi AR, Bihamta MR (2025) Seed priming with salicylic acid
749 enhances salt stress tolerance by boosting antioxidant defense in Phaseolus vulgaris genotypes. BMC
750 Plant Biology, 25:489. https://doi.org/10.1186/s12870-025-06376-2

751 Lacerda CN, Lima GS, Soares LAA, Arruda TFL, Silva AAR, Gheyi HR, Dantas MV, Ferreira JTA (2025)
752 Foliar application of ascorbic acid in guava cultivation under water replacement levels. Revista
753 Caatinga, 38:12595. https://doi.org/10.1590/1983-21252025v3812595rc
754 Lanza MGD, Bereta RAR (2021) Roles of selenium in mineral plant nutrition: ROS scavenging responses
755 against abiotic stresses. Plant Physiology and Biochemistry, 164:27-43.
756 https://doi.org/10.1016/j.plaphy.2021.04.026
757 Lima GS, Silva JB, Pinheiro FWA, Soares LAA, Gheyi HR (2020) Potassium does not mitigate saline
758 stress in yellow passion fruit under irrigation management strategies. Revista Caatinga, 33:1082-1091.
759 https://doi.org/10.1016/j.plaphy.2021.04.026
760 Liu C, Jiang X, Yuan Z (2024) Plant responses and adaptations to salt stress: a review. Horticulturae,
761 10:1221. https://doi.org/10.3390/horticulturae10111221
762 Lopes BG (2023) Estimação do tamanho ótimo de parcela e uso de medidas de não linearidade na validação
763 de modelos em experimentos com Passiflora. Doutorado, Universidade de São Paulo, Piracicaba.
764 Maas EV, Hoffman GJ (1977) Crop Salt Tolerance-Current Assessment. Journal of the Irrigation and
765 Drainage Division, 103:115-134. https://doi.org/10.1061/JRCEA4.0001137
766 Macêdo EG, Alves AC, Jesus FN, Silva JM, Lopes MVS, Souza AA (2025) Água salina e esterco bovino
767 no cultivo de mudas de maracujazeiro amarelo (*Passiflora edulis flavicarpa*). Agropecuária Científica
768 do Semiárido, 21:20-27. https://doi.org/10.30969/n0x4c669
769 Medeiros JF (1992) Qualidade da água de irrigação e evolução da salinidade nas propriedades assistidas
770 pelo" GAT" nos Estados do RN, PB e CE. Dissertação, Universidade Federal da Paraíba – PB.
771 Mishra S, Sharma A, Srivastava AK (2024) Ascorbic acid: A metabolite switch for designing stress-smart
772 crops. Critical Reviews in Biotechnology, 44:1350-1366.
773 https://doi.org/10.1080/07388551.2023.2286428
774 Muhammad M, Waheed A, Wahab A, Majeed M, Nazim M, Liu YH, Li WJ (2024) Soil salinity and drought
775 tolerance: An evaluation of plant growth, productivity, microbial diversity, and amelioration
776 strategies. Plant Stress, 11:100319. https://doi.org/10.1016/j.stress.2023.100319
777 Nawaz M, Ashraf MY, Khan A, Nawaz F (2021) Salicylic acid–and ascorbic acid–induced salt tolerance
778 in mung bean (*Vigna radiata* (L.) Wilczek) accompanied by oxidative defense mechanisms. Journal
779 of Soil Science and Plant Nutrition, 21:2057-2071. https://doi.org/10.1007/s42729-021-00502-3
780 Nedjimi B (2024) Selenium as a powerful trace element for mitigation of plant salt stress: A review. Journal
781 of Trace Elements and Minerals, 8:100123. https://doi.org/10.1016/j.jtemin.2024.100123
782 Novais RF, Neves JCL, Barros NF (1991) Ensaio em ambiente controlado. In: Oliveira AJ, Garrido WE,
783 Araújo JD, Lourenço S (eds.) Métodos de pesquisa em fertilidade do solo. Brasília, Embrapa-SEA, p.
784 189- 254.
785 Pinheiro FWA, Lima GS, Gheyi HR, Soares LAA, Nobre RG, Fernandes PD (2022) Brackish water
786 irrigation strategies and potassium fertilization in the cultivation of yellow passion fruit. Ciência e
787 Agrotecnologia, 46:022621. https://doi.org/10.1590/1413-7054202246022621
788 Richards LA (1954) Diagnosis and improvement of saline and alkali soils. Agriculture Handbook 60, U. S.
789 Department of Agriculture, 60p.

790 Saleem MA, Khan A, Tu J, Huang W, Liu Y, Feng N, Xue Y (2025) Salinity Stress in Rice: Multilayered
791 Approaches for Sustainable Tolerance. International Journal of Molecular Sciences, 261:6025.
792 https://doi.org/10.3390/ijms26136025
793 Santos LFS, Lima GS, Lima VLA, Silva AAR, Fátima RT, Arruda TFL, Capitulino JD (2024) Proline in
794 inducing tolerance to saline stress in passion fruit seedlings. Revista Caatinga, 37:12048-e12048.
795 https://doi.org/10.1590/1983-21252024v3712048rc
796 Santos ST, Oliveira FA, Oliveira GBS, Sá FVS, Costa JPBM, Fernandes PD (2020) Photochemical
797 efficiency of basil cultivars fertigated with salinized nutrient solutions. Revista Brasileira de
798 Engenharia Agrícola e Ambiental, 24:319-324. https://doi.org/10.1590/1807-
799 1929/agriambi.v24n5p319-324
800 Saritha K, Vijaya D, Rao BS, Padma M (2017) Relative salt tolerance of different grape rootstocks to
801 different chloride salts. Intenational Journal of Current Microbiology and Applie Sciences, 6:24-33.
802 https://doi.org/10.20546/ijcmas.2017.611.003
803 Scotti-Campos P, Pham-Thi AT, Semedo JN, Pais IP, Ramalho JC, Matos MC (2013) Physiological
804 responses and membrane integrity in three Vigna genotypes with 39 contrasting drought tolerance.
805 Emirates Journal of Food and Agriculture, 25:1002-1013, 2013.
806 https://doi.org/10.9755/ejfa.v25i12.16733
807 Sharma A, Kumar M, Sharma P (2024) Environmental Challenges in Attaining Food Security. Elsevier.
808 Silva AARd, Lima GSd, Azevedo CAVd, Veloso LLdSA, Gheyi HR. (2020). Salicylic acid as an attenuator
809 of salt stress in soursop. Revista Caatinga, 33: 1092-1101.
810 Silva ACZ, Pereira RF, Ferreira RS, Alves SB, Sousa SF, Rodrigues SS, Brito Neto JF, Melo AS, Silva
811 RM, Mesquista EF (2025a) Silicon and potassium synergistically alleviate salt stress and enhance soil
812 fertility, nutrition, and physiology of passion fruit seedlings. Frontiers in Plant Science, 16:1685221.
813 https://doi.org/10.3389/fpls.2025.1685221
814 Silva JCA, Nobrega JS, Lima GS, Soares LAA, Ferreira JTA, Almeida DC, Silva GS, Silva JS, Lacerda C.
815 N, Silva SS, Silva AAR, Gheyi HR, Dantas MV (2025b) Ascorbic acid on the induction of salt stress
816 tolerance in guava in the seedling formation phase. Plant Physiology and Biochemistry, 220:109506.
817 https://doi.org/10.1016/j.plaphy.2025.109506
818 Silva Júnior CA, D'Amico-Damião V, Carvalho RF (2021) Família do fitocromo tipo B: O sinalizador de
819 respostas ao estresse abiótico nas plantas. Anais de Biologia Aplicada, 178:135-148.
820 Souza AR, Azevedo CAV, Borborema LDA, Lima GS, Soares LAA, Silva AAR, Nunes KG, Costa DS,
821 Durval PHD, Arruda TFL, Sales RD, Cruz PMD, Farias BJP, Gheyi HR, Lima VLA, Ramos, J. G
822 (2026) Foliar Application of Selenium in Mitigating Salinity Stress on the Physiology, Growth, and
823 Yield of Okra. Plants, 15:21. https://doi.org/10.3390/plants15010021
824 Sun C, Sida M, Baofeng W, Siting Z, Yulong L, Mingfang Q, Zhenqi W, Zepeng Y, Tianlai L (2023)
825 Exogenous melatonin enhances tomato heat resistance by regulating photosynthetic electron flux and
826 maintaining ROS homeostasis. Plant Physiology and Biochemistry, 196:197-209.
827 https://doi.org/10.1016/j.plaphy.2023.01.043
828 Teixeira PC, Donagemma GK, Fontana A, Teixeira WG (2017) Manual de métodos de análise de solo.
829 3.ed. Brasília: Embrapa, 573p.

Thabet SG, Safhi FA, Börner A, Alqudah AM (2025) Genetic insights into intergenerational stress memory and salt tolerance mediated by antioxidant responses in wheat. Journal of Soil Science and Plant Nutrition, 25:843-857. https://doi.org/10.1007/s42729-024-02170-5

Torres RA, Nóbrega JS, Lima GS, Soares LAA, Ferreira JT, Dantas MV, Gheyi HR, Roque IA (2025) Ascorbic acid as an elicitor of salt stress on the physiology and growth of guava. Revista Caatinga, 38:12425. https://doi.org/10.1590/1983-21252025v3812425rc

Wang YH, Zhang G, Chen Y, Gao J, Sun YR, Sun MF, Chen JP (2019) Exogenous application of gibberellic acid and ascorbic acid improved tolerance of okra seedlings to NaCl stress. Acta Physiologiae Plantarum, 41:93. https://doi.org/10.1007/s11738-019-2869-y

Weatherley PE (1950) Studies in the water relations of the cotton plant. I. The field measurement of water deficits in leaves. New Phytologist, 49:81-97. https://doi.org/10.1111/j.1469-8137.1950.tb05146.x

Wu P, li B, Liu Y, Bian Z, Xiong J, Wang YX, Zhu B (2024) Multiple physiological and biochemical functions of ascorbic acid in plant growth, development, and abiotic stress response. International Journal of Molecular Sciences, 25:1832. https://doi.org/10.3390/ijms25031832

Wu R, Sun X, Zhu M, Wang Y, Zhu Y, Fang Z, Du S. (2025) Abscisic acid-producing bacterium Azospirillum brasilense effectively reduces heavy metals (cadmium, nickel, lead, and zinc) accumulation in pak choi across various soil types. Ecotoxicology and Environmental Safety, 298: 118277.

Zhou H, Shi H, Yang Y, Feng X, Chen X, Xiao F, Lin H, Guo Y (2024) Insights into plant salt stress signaling and tolerance. J. Genet Genomics, 51:16-34. https://doi.org/10.1016/j.jgg.2023.08.007

Zulfiqar F, Ashraf M (2021) Nanoparticles potentially mediate salt stress tolerance in plants. Plant Physiology and Biochemistry, 160:257-268. https://doi.org/10.1016/j.plaphy.2021.01.028