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Effect of priming guava seeds with H_2O_2 on seedling production under salt stress

Efeito do condicionamento de sementes de goiabeira com H_2O_2 na produção de mudas sob estresse salino

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Highlights

H_2O_2 at 25 μM accelerates the emergence of guava 'Paluma' seedlings.
Salt stress reduces photosynthetic pigments in the 'Paluma' guava plant.
H_2O_2 increases the ESI of 'Paluma' guava seedlings but does not mitigate salt stress.

Abstract

Guava is one of the most economically important fruit crops grown in the Northeast region of Brazil. This region is characterized by a high concentration of salts in the water sources used for irrigation, necessitating the development of strategies to minimize the harmful effects of salt stress on production systems. The objective of this study was to analyze the effect of priming guava seeds with H_2O_2 on seedling production under salt stress. The experiment was conducted in a greenhouse at the Center for Agri-food Science and Technology at the Federal University of Campina Grande, located in Pombal, PB, Brazil. A randomized complete block experimental design was employed, involving a 5 × 3 factorial arrangement represented by five levels of electrical conductivity of irrigation water (ECw: 0.3, 1.1,

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1.9, 2.7, and 3.5 dS m^{-1}) and three concentrations of hydrogen peroxide (H_2O_2: 0, 25, and 50 μM). Four replications were used, with five plants per plot. Salinity in the water starting from 0.3 dS m^{-1} reduced growth, relative water content, photosynthetic pigments, dry biomass, and Dickson's quality index, and increased the water saturation deficit in 'Paluma' guava seedlings 110 days after sowing. Hydrogen peroxide at a concentration of 25 μM increased the emergence speed index of seedlings, although its application at a concentration of up to 50 μM did not alleviate the adverse impacts of salt stress on 'Paluma' guava seedlings under an electrical conductivity of irrigation water of 3.5 dS m^{-1}.

Key words: Abiotic stress. Fruit farming. Mitigation. *Psidium guajava* L. Salinity.

Resumo

A goiabeira é uma das fruteiras de maior importância socioeconômica explorada na região Nordeste do Brasil. No entanto, essa região é marcada pela concentração de sais nas fontes hídricas utilizadas para irrigação, tornando necessário o desenvolvimento de estratégias para minimizar os efeitos prejudiciais do estresse salino nos sistemas de produção. Objetivou-se com o presente estudo analisar os efeitos da pré-exposição de sementes de goiabeira cv. Paluma ao peróxido de hidrogênio na tolerância ao estresse salino. A pesquisa foi realizada em casa de vegetação, no Centro de Ciências e Tecnologia Agroalimentar da Universidade Federal de Campina Grande, Pombal, PB. O delineamento utilizado foi em blocos casualizados em arranjo fatorial 5 × 3, com cinco níveis de condutividade elétrica da água de irrigação - CEa (0,3; 1,1; 1,9; 2,7 e 3,5 dS m^{-1}) e três concentrações de peróxido de hidrogênio - H_2O_2 (0, 25 e 50 μM), com quatro repetições e cinco plantas por parcela. A salinidade da água a partir de 0,3 dS m^{-1} promove decréscimo no crescimento, no conteúdo relativo de água, nos pigmentos fotossintetizantes, na fitomassa seca, no índice de qualidade de Dickson e aumenta o déficit de saturação hídrica das mudas de goiabeira 'Paluma' aos 110 dias após a semeadura. O peróxido de hidrogênio na concentração de 25 μM aumenta o índice de velocidade de emergência das mudas e a sua aplicação em uma concentração de até 50 μM, não proporciona alívio aos impactos adversos do estresse salino em mudas de goiabeira da variedade Paluma, sob condutividade elétrica da água de irrigação de 3,5 dS m^{-1}.

Palavras-chave: Estresse abiótico. Fruticultura. Mitigação. *Psidium guajava* L. Salinidade.

Introduction

Guava (*Psidium guajava* L.), a member of the Myrtaceae family, is widely cultivated in tropical and subtropical countries. It is one of the main fruit crops of socioeconomic importance in the Northeast region of Brazil (Morais-Braga et al., 2016), with a harvested area of 10,788 ha and a production of 281,524 t, accounting for 49.84% of Brazilian fruit production (Instituto Brasileiro de Geografia e Estatística [IBGE], 2022).

Despite its agricultural potential, the semiarid region of Northeast Brazil is recognized for its irregular rainfall distribution, low precipitation rates, and high evaporation rates. These factors contribute to soil salinity accumulation, which compromises plant growth and development and hinders the expansion of cultivation areas. Furthermore, local farmers rely on subterranean water for irrigation, many sources of which contain high salt concentrations, exacerbating soil salinity and resulting in low yields for various crops (Freire et al., 2014; Lima et al., 2019).

Under stressful conditions, the guava plant can exhibit physiological disorders such as stomatal closure, degradation of photosynthetic pigments, and changes in fluorescence signals, which result in reduced growth and poor developmental performance (E. M. da. Silva et al., 2017; I. L. Bezerra et al., 2018; Bonifácio et al., 2018). Additionally, exposure to high levels of salt can trigger oxidative stress due to the formation of reactive oxygen species (ROS), which can impair chlorophyll production, damage cellular structures, and induce membrane lipid peroxidation (Andrade et al., 2022; Pinheiro et al., 2022).

The application of hydrogen peroxide (H_2O_2) is an alternative strategy to minimize the effects of salt stress on plants. It can aid in adaptation to salt stress through metabolic changes that increase plant tolerance to future stress exposures (Gohari et al., 2020). The exogenous application of low concentrations of H_2O_2 during seed imbibition can improve the plant's antioxidant system by acting on ROS to neutralize their action or prevent their formation, thus reducing cellular damage (E. M. da Silva et al., 2016; A. A. R. Silva et al., 2019).

Research on the application of H_2O_2 to mitigate the effects of salt stress on the cultivation of different fruit species, including *Annona muricata* L. (A. D. Silva et al., 2022; Capitulino et al., 2024), *Passiflora edulis* Sims (Pinheiro et al., 2022), and *P. guajava* L. (Rodrigues et al., 2023b), has predominantly focused on foliar applications at various concentrations. However, these studies have not specifically addressed the effects of a targeted concentration of H_2O_2 during the imbibition of guava seeds. Therefore, the objective of this study was to analyze the effects of pre-exposing Paluma guava seeds to hydrogen peroxide on their salt stress tolerance.

Material and Methods

The research was conducted from September to December 2022 in a greenhouse at the Center for Agri-food Science and Technology (CCTA) at the Federal University of Campina Grande (UFCG), located in Pombal, Paraíba, Brazil, at geographic coordinates 6° 47′ 20″ S and 37° 48′ 01″ W, at an altitude of 184 m. The region's climate is classified as "BSh" according to the Köppen climate classification adapted for Brazil, indicative of a hot and semiarid climate (Alvares et al., 2013). The average annual temperature is 28 °C, with approximately 750 mm of rainfall and an average annual evaporation of 2,000 mm. Figure 1 shows the temperature and relative humidity data recorded during the experimental period.

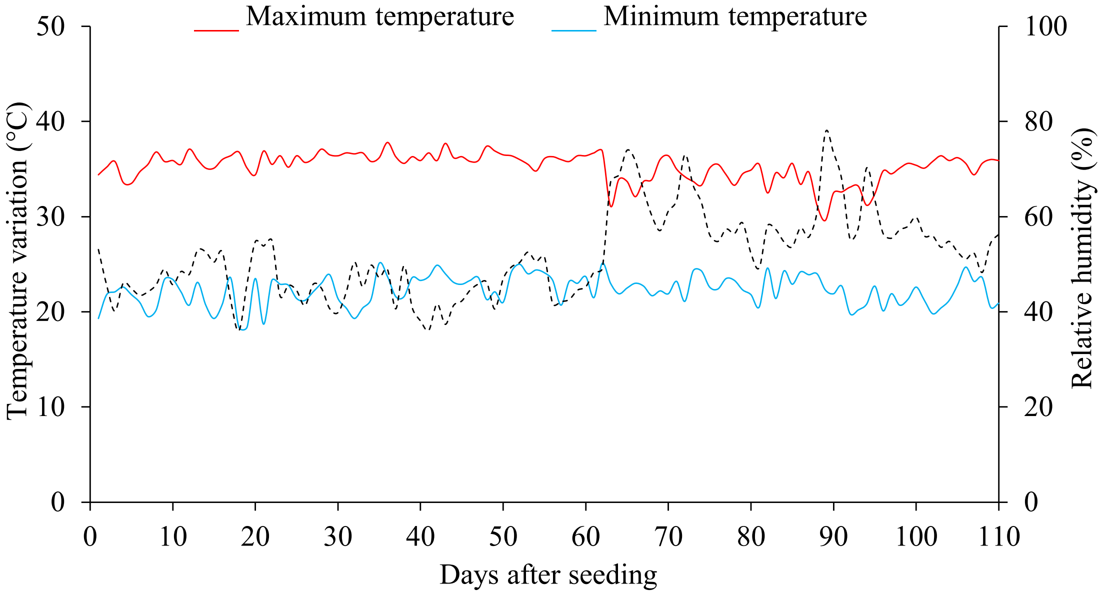

Figure 1. Variation in maximum and minimum temperature (ºC) and relative humidity (%) during the seedling growth period. Pombal-PB, 2022.

The experimental design was a randomized complete block design in a 5 × 3 factorial arrangement, involving five levels of electrical conductivity of irrigation water (ECw: 0.3, 1.1, 1.9, 2.7, and 3.5 dS m^{-1}) and three concentrations of hydrogen peroxide (H_2O_2: 0, 25, and 50 µM) during seed imbibition, with four replications and five plants per plot, totaling 300 plants. The salinity levels were based on research by Bonifácio et al. (2018), while the hydrogen peroxide concentrations were determined from the study by Silva et al. (2018).

Seeds of the Paluma cultivar were acquired from the orchard in the fruit growing sector of the CCTA-UFCG Experimental Farm, Pombal Campus. The concentrations of H_2O_2 were prepared by diluting in distilled water and stored in a dark environment to subsequently imbibe the seeds. Prior to sowing, the seeds were soaked in 0, 25, and 50 µM H_2O_2 concentrations for 24 h in the dark in beakers covered with aluminum foil under BOD (Biological Oxygen Demand) conditions at 25 °C (A. A. R. Silva et al., 2019).

Three seeds were sown per container in 10 x 18 cm polyethylene bags. The substrate used was Regosol (Entisols - Psamments) with a sandy-loam texture, mixed with cured cattle manure (2:1, v:v). Soil samples were collected at a depth of 0.30 cm in an agricultural area in the municipality of Pombal, Paraíba, Brazil. Table 1 describes the physical and chemical characteristics of the soil, determined following the methods outlined by Teixeira et al. (2017).

Table 1
Chemical and physical characteristics of the soil used in the experiment, before the implementation of treatments. Pombal, 2022

Chemical characteristics								
pH H_2O) (1:2.5)	OM g kg^{-1}	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+
			$cmol_c$ kg^{-1}					
5.58	2.93	39.2	0.23	1.64	9.07	2.78	0.0	8.61
Chemical characteristics				Physical characteristics				
EC_{es}	CEC	SAR_{se}	ESP	Particle size fraction (g kg^{-1})			Moiture (dag kg^{-1})	
(dS m^{-1})	$cmol_c$ kg^{-1}	(mmol $L^{-1})^{0,5}$	%	Sand	Silt	Clay	33.42	1519.5
							kPa^2	
2.15	22.33	0.67	7.34	572.7	100.7	326.6	25.91	12.96

pH - potential of hydrogen; OM - organic matter, Walkley-Black wet digestion; Ca^{2+} and Mg^{2+} extracted with 1 M KCl, pH 7.0; Na^+ and K^+ extracted using 1M NH_4OAc, pH 7.0; Al^{3+} + H^+ extracted using 0.5 M CaOAc, pH 7.0; ECse - electrical conductivity of the saturation extract; CEC - cation exchange capacity; SARse - sodium adsorption ratio of the saturation extract; ESP - exchangeable sodium percentage; 1.2 referring to the moisture content in the soil corresponding to field capacity and permanent wilting point.

Nitrogen, phosphorus, and potassium applications adhered to guidelines from Cavalcanti (2008) considering the nutritional requirements of the crop and existing soil nutrient levels. Three foliar applications were made 60 days after sowing, applying 100, 300, and 150 mg kg^{-1} of soil of N, P_2O_5, and K_2O, respectively, using tap water (0.3 dS m^{-1}). The nitrogen source was urea, MAP was used for phosphorus and as a complementary nitrogen source, and potassium chloride (K_2O) was used for potassium.

Different levels of water salinity were achieved by adding NaCl according to predetermined treatments. The water source was from the Pombal - PB supply system, with an electrical conductivity of 0.3 dS m^{-1}. The amount of NaCl was calculated based on the relationship between the electrical conductivity of the water and the salt concentration, using Equation 1. Salt concentrations were always prepared before application.

$$SC \approx 10 \times ECw \quad (1)$$

where SC refers to the sum of cations ($mmol_c$ L^{-1}); and ECw refers to the electrical conductivity of the water (dS m^{-1}).

After preparing the water, the ECw was checked and adjusted as necessary before use. Before sowing, the volume of water required to raise the soil moisture to field capacity was determined by applying water based on the established treatments. This was calculated based on the water requirement of the crop, determined by the difference between the applied volume and the volume drained every 20 days, maintaining the soil near field capacity using Equation 2. Irrigation was performed daily at

17:00, applying the volume determined by the water balance in each bag.

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

where VI = volume of water to be used in the next irrigation event (mL); Va = volume applied in the previous irrigation (mL); Vd = volume drained (mL); and LF = leaching fraction of 0.10, applied every 20 days.

For the emergence speed index (ESI), only the factor of hydrogen peroxide concentrations was considered, as the application of levels of electrical conductivity of irrigation water had not yet commenced. The number of emerged seedlings was recorded daily from the 13th to the 33rd day. Using the daily data of the number of normal seedlings, the ESI was calculated through Equation 3 (Maguire, 1962).

$$ESI = \frac{G1}{N1} + \frac{G2}{N2} + \ldots \frac{Gn}{Nn} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where: ESI = emergence speed index; G1, G2, ... Gn = number of emerged seedlings counted in the first, second, ... and last count; and N1, N2, ... Nn = number of days from sowing to the first, second, ..., and last count.

After 110 days from emergence, several parameters were evaluated to assess the effects of treatments on guava seedlings. Growth measurements included plant height (PH) measured with a ruler; stem diameter (SD) measured with a digital caliper; number of leaves (NL); and leaf area (LA). Leaf area was calculated according to the method described by Lima et al. (2015), as shown in Equation 4.

$$LA = \sum 0.3205 \times C^{2.0412} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where LA = total leaf area (cm^2); and C = length of main leaf vein (cm).

For leaf water status determination, three fully expanded leaves were used. Leaf discs (113 mm^2) were taken to determine the relative water content (RWC) and leaf water saturation deficit (LWSD), weighed on an analytical balance. Immediately after collection, fresh weight (FW) was determined. The samples were then placed in plastic bags, immersed in distilled water, and incubated for 24 h. Excess water was removed with paper towels to obtain the turgid weight (TW); subsequently, the samples were dried in a circulating air oven (temperature ≈ 65 °C ± 3 °C, until constant weight) to obtain the dry weight (DW). The relative water content and LWSD were determined according to Smart and Bingham (1974) and Lima et al. (2015), using Equations 5 and 6, respectively.

$$RWC = \frac{FW - DW}{TW - DW} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$LWSD = \frac{TW - FM}{TW - DW} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where RWC = relative water content (%); LWSD = leaf water saturation deficit (%); FW = fresh leaf weight (g); TW = turgid weight (g); and DW = dry weight (g).

Chlorophyll a, b, total chlorophyll, and carotenoid contents were measured using the analytical method recommended by Arnon (1949). Samples consisted of five leaf disks taken from the third mature leaf from the apex. Concentrations were determined in an 80% acetone solution using a spectrophotometer at absorbance wavelengths of 470, 646, and 663 nm, through Equations 7, 8, and 9, respectively.

$$\text{Chlorophyll } a \text{ (Cl } a) = (12.25 \text{ ABS}_{663}) - (2.81 \text{ ABS}_{646}) \quad (7)$$

$$\text{Chlorophyll } b \text{ (Cl } b) = (21.50 \text{ ABS}_{646}) - (5.10 \text{ ABS}_{663}) \quad (8)$$

$$\text{Carotenoid (Car)} = (1000 \text{ ABS470} - 1.82 \text{ Cl a} - 85.02 \text{ Cl b}) / 198 \quad (9)$$

where ABS = absorbance.

The accumulation of dry biomass for each plant was ascertained by drying samples in a forced air circulation oven at a temperature of 65 °C, followed by weighing on an analytical balance (g per plant). Root length (RL) was measured from the plant's neck to the root apex using a ruler (cm). The quality of the seedlings was assessed using the Dickson Quality Index (DQI) (Dickson et al., 1960), through Equation 10.

$$\text{DQI} = \frac{\text{TDB}}{(\text{PH/SD}) + (\text{ShDB/RDB})} \quad (10)$$

where PH = plant height (cm); SD = stem diameter (mm); TDB = total dry biomass (g); ShDB = shoot dry biomass (g); and RDB = root dry biomass (g).

The data were subjected to an analysis of variance using the F test ($p \leq 0.05$). When significant, polynomial regression analysis was conducted for water electrical conductivity, and Tukey's test ($p \leq 0.05$) was applied for H_2O_2 concentrations, using the statistical software SISVAR (D. F. Ferreira, 2019).

Results and Discussion

The salinity levels of the irrigation water significantly impacted the development of guava seedlings, affecting leaf number, leaf area, plant height, stem diameter, chlorophyll a, carotenoids, relative water content, water saturation deficit, root length, shoot dry biomass, root dry biomass, and Dickson's quality index. Conversely, H_2O_2 concentrations influenced the emergence speed and Dickson's quality indices. The interaction between salinity levels and H2O2 concentrations only affected carotenoid levels.

The seed emergence speed index was higher at H_2O_2 concentrations of 25 and 50 μM, showing increases of 7.7% and 16.5%, respectively, compared to lower quantified indices (Figure 2). This behavior may be associated with cellular signaling, where reactive oxygen species (ROS) interact with other molecules, particularly in the regulation of phytohormones such as auxin (IAA), abscisic acid (ABA), gibberellins (GAs), brassinosteroids (BRs), and nitric oxide (NO). These phytohormones play roles in activating or inhibiting growth and development processes during initial embryogenesis, as well as in mechanisms related to root protrusion and germination (Stein et al., 2021; Hernández Cortés, 2022). Similarly, Panngom et al. (2018) observed an increase in the speed and percentage of germination in Daucus carota L. seeds soaked in concentrations of 25 and 50 mM H_2O_2, and Souza et al. (2023) reported similar findings in Khaya ivorensis seeds (24.2 mM).

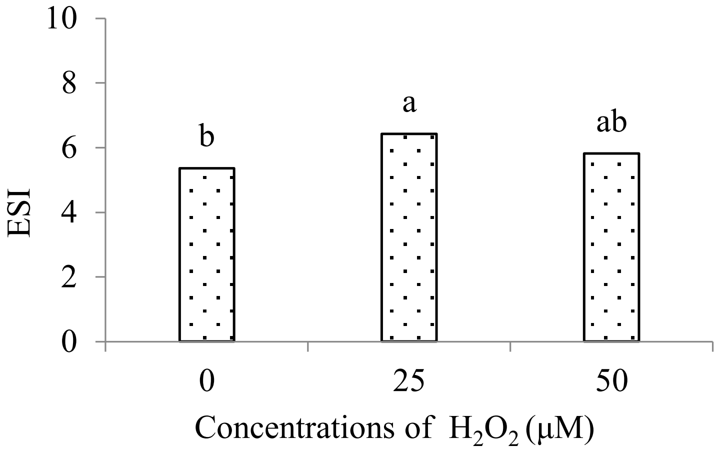

Figure 2. Emergence speed index (ESI) of 'Paluma' guava seedlings as a function of hydrogen peroxide concentrations at 110 days after sowing.

The number of leaves (NL), leaf area (LA), plant height (PH), and stem diameter (SD) of guava seedlings decreased linearly with increasing electrical conductivity of the irrigation water (Figure 3), showing decreases of 14.17%, 15.69%, 10.19%, and 7.26%, respectively, per unit increase in ECw. Analyzing NL (Figure 3A), LA (Figure 3B), PH (Figure 3C), and SD (Figure 3D) in relative terms, there was a reduction of 47.4%, 52.7%, 33.7%, and 23.8%, respectively, in plants grown under a higher ECw level of 3.5 dS m^{-1}, compared to those receiving water with lower conductivity of 0.3 dS m^{-1}, at 110 days after sowing.

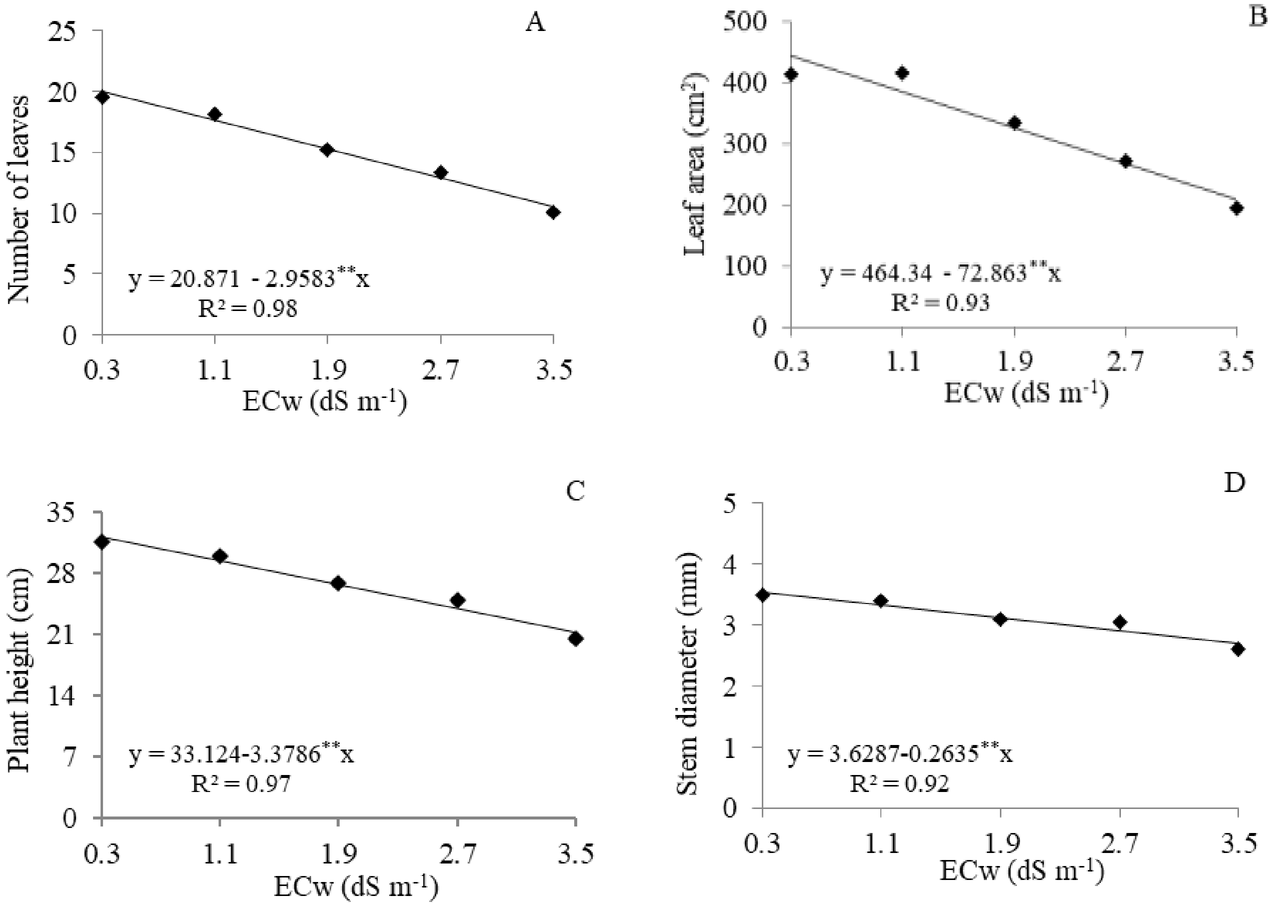

Figure 3. Number of leaves (A), leaf area (B), plant height (C), and stem diameter (D) of 'Paluma' guava seedlings as a function of water electrical conductivity levels (ECw) at 110 days after planting seeding.
*, ** - significant at $p \leq 0.05$ and at $p \leq 0.01$ by the F test, respectively.

The growth reductions observed in this research may have occurred due to excessive accumulation of salts in the root zone of plants, as excess salts can increase ion concentrations in the soil solution, leading to decreased water availability for plants. This happens through osmosis, a process in which water moves from the soil into the roots to balance ion concentration levels. When there are high salt concentrations in the soil solution, water absorption by the roots can become difficult, resulting in water stress for the plant. Furthermore, the accumulation of salts can directly damage plant roots and interfere with the absorption of essential nutrients, as highlighted in studies by Taiz et al. (2017), Byrt et al. (2018), and Sá et al. (2019).

Rodrigues et al. (2023a) conducted a study with 'Paluma' guava seedlings in the seedling formation phase, irrigated with waters of different cationic nature and treated with salicylic acid. They also observed a linear reduction in the number of leaves (14.9%), leaf area (15.54%), plant height (9.76%), and stem diameter (8.94%) when comparing plants irrigated with higher (3.5 dS m^{-1}) and lower (0.3 dS m^{-1}) ECw at 125 DAS. In another study, Rodrigues et al. (2023b) evaluated the morphology of ‘Crioula’ guava irrigated with water with increasing salinity and nitrogen-potassium fertilization, finding that irrigation water with ECw above 0.3 dS m^{-1} reduced stem diameter, leaf area, and plant height in ‘Crioula’ guava seedlings.

Xavier et al. (2022) also described a linear reduction in growth rate as ECw levels increased when using saline waters of higher concentration (ECw: 0.6 to 4.3 dS m^{-1}) to irrigate ‘Paluma’ guava seedlings in the rootstock formation phase. These seedlings were prepared with Na^+, Ca^{2+}, and Mg^{2+} in a ratio equivalent to 7:2:1.

The electrical conductivity of irrigation water had a negative impact on chlorophyll a (Chl *a*) content in ‘Paluma’ guava at 110 DAS. Using the regression equation (Figure 4A), a decrease of 7.91% in Chl *a* content was observed for each unit increase in ECw. In relative terms, plants irrigated with water at 3.5 dS m^{-1} exhibited a reduction of 25.94% (4.52 mg g^{-1} FW) in Chl *a* content compared to those irrigated with an ECw of 0.3 dS m^{-1}. Similarly, Pinheiro et al. (2022) reported that irrigation water salinity (4.0 dS m^{-1}) resulted in reduced Chl *a* and Chl *b* levels in *Passiflora edulis* Sims.

The decrease in chlorophyll levels may result from the degradation of these pigment molecules by the enzyme chlorophyllase, as well as from reduced chlorophyll production caused by high salinity (Nunkaew et al., 2014). Salt stress inhibits the formation of 5-aminolevulinic acid, a precursor of chlorophyll, which in turn activates chlorophyllase (Taiz et al., 2017), an enzyme involved in the breakdown of photosynthetic pigment molecules. Additionally, chlorophyll degradation may be related to photooxidation induced by secondary oxidative stress (Freire et al., 2013).

Carotenoid content was influenced by the interaction between H_2O_2 concentrations and ECw. Plants subjected to a combination of 0, 25, and 50 μM of H_2O_2 with a lower salinity level of 0.3 dS m^{-1} exhibited the highest carotenoid content, with values of 6.16, 6.46, and 6.89 mg g^{-1} FW, respectively (Figure 4B). On the other hand, the lowest carotenoid levels were measured with increasing salinity levels up to 3.5 dS m^{-1} and with H_2O_2 concentrations of 0 and 50 μM, showing a reduction of 6.97 and 6.96%, respectively.

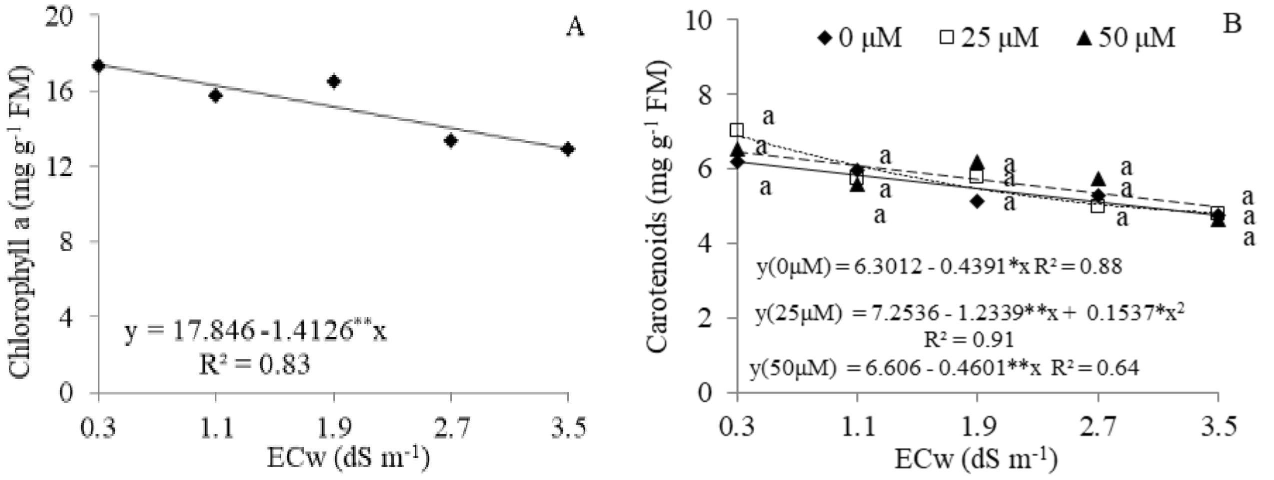

Figure 4. Chlorophyll a (A) contents as a function of the electrical conductivity of irrigation water and carotenoids (B) as a function of the interaction between the electrical conductivity levels of the water (ECw) and hydrogen peroxide, of guava seedlings at 110 days after the sowing.
*, ** - significant at $p \leq 0.05$ and at $p \leq 0.01$ by the F test, respectively.

Carotenoids act between light absorption complexes and the lipid layer of thylakoid membranes, resulting in reduced membrane fluidity and susceptibility to lipid peroxidation (Taiz et al., 2017). Thus, the decrease in carotenoid content may indicate potential degradation of β-carotene and a reduction in zeaxanthin production (Taïbi et al., 2016). Dito and Gadallah (2019) suggest that an adequate concentration of H_2O_2 (10 µM) can activate antioxidant enzymes that help reduce oxidative damage and improve plant physiological aspects under stress conditions. In other words, H_2O_2 can act as a signaling molecule.

Corroborating the results of this study, Capitulino et al. (2024) identified a reduction in the impact of salt stress on carotenoid levels through the application of H_2O_2 in *Annona muricata* L. Concentrations between 10 and 16 µM of H_2O_2 reduced the salinity effect to levels of 1.6 and 2.0 dS m^{-1}, respectively, 370 days after transplanting.

Irrigation with saline water had a negative impact on the relative water content (RWC) of 'Paluma' guava, which declined slightly by 1.34% with each unit increase in ECw (Figure 5A). When comparing the RWC of plants subjected to an ECw of 3.5 dS m^{-1} with those irrigated with the lowest level, a decrease of 4.32% is observed. Lacerda (2022), in a study of 'Paluma' guava under salt stress, identified a decrease in leaf turgor of 4.03%. This reduction may be due to disturbances in the plant's water balance, induced by the reduced water availability resulting from increased salinity (Barreiro et al., 2017).

In terms of water saturation deficit, plants irrigated with an ECw of 3.5 dS m^{-1} exhibited a 22.72% increase compared to those irrigated with an ECw of 0.3 dS m^{-1}

(Figure 5B), with a linear increase of 9.44% per unit increment in ECw. According to Garcia et al. (2009) and Bonifácio et al. (2018), the observed increase may reflect the toxic effects of salts absorbed by the plants, especially Na^+ and Cl^-, in the cells, and the reduction of total water potential due to the increase in salt concentration. Furthermore, as a consequence of osmotic imbalance, there is a reduction in the relative water content due to the pronounced accumulation of salts, as evidenced by the RWC of the guava seedlings (Figure 5A).

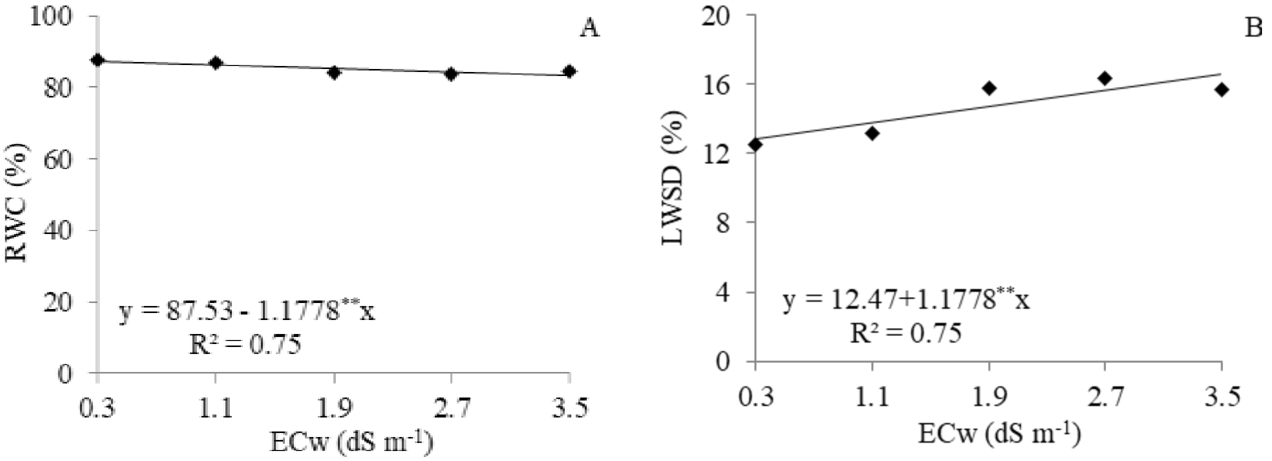

Figure 5. Relative water content (RWC - A) and water saturation deficit (LWSD - B) of 'Paluma' guava seedlings as a function of the electrical conductivity levels of irrigation water (ECw) at 110 days after sowing.
*, ** - significant at $p \leq 0.05$ and at $p \leq 0.01$ by the F test, respectively.

Root length decreased linearly with increasing salinity of the irrigation water, showing an 8.24% decline per unit increase in ECw. Comparing root lengths at different salinity levels from 3.5 dS m^{-1} to 0.3 dS m^{-1}, there was a reduction of 27.06% (Figure 6A). Additionally, the values for shoot dry mass (SDM) and root dry mass (RDM) also displayed a decreasing linear trend, with reductions of approximately 17.04% and 17.82% per unit increase in ECw (Figures 6B and 6C).

Kang et al. (2014) associate the overall decrease in crop growth and yield under salt stress with the cumulative effects of disruption of ionic homeostasis, water imbalance, and reduction in plant photosynthetic capacity. Consequently, the reduction in biomass accumulation with increasing ECw may be associated with the observed reduction in photosynthetic pigments (Figure 4A). According to studies by L. M. Oliveira (2019) and J. D. Bezerra et al. (2016), this occurs due to the reduction in osmotic potential caused by the accumulation of salts in the soil solution, as a result of constant irrigation with high electrical conductivity water, which directly or indirectly affects physiological processes. Nóbrega et al. (2017) also observed a decrease in the SDM and RDM of guava seedlings irrigated with different types of water with an electrical conductivity of 2.75 dS m^{-1}, evaluating the initial development of the plants.

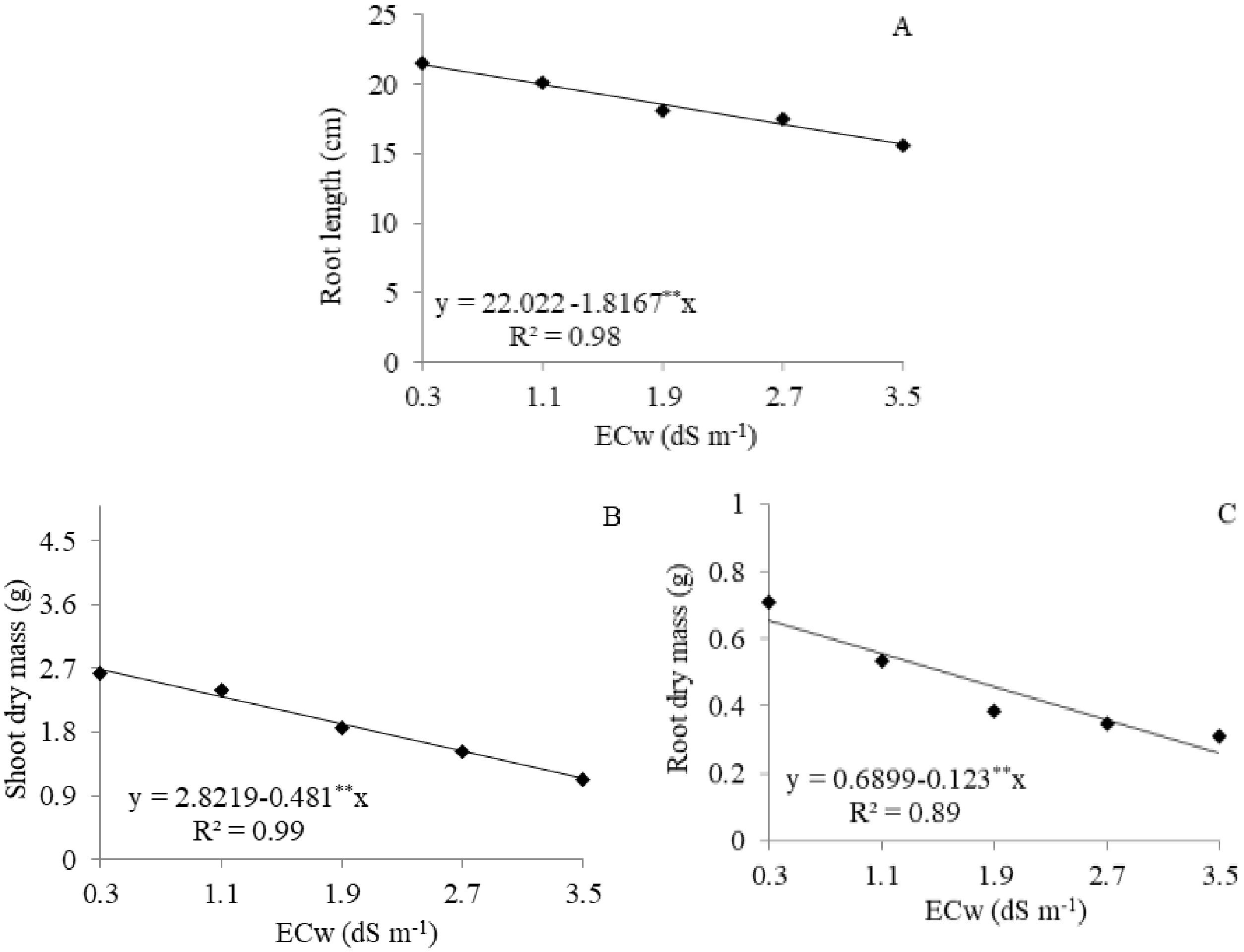

Figure 6. Root length (A), shoot dry mass (B), and root dry phytomass (C) of 'Paluma' guava seedlings as a function of water electrical conductivity levels (ECw) at 110 days after planting seeding.
*, ** - significant at $p \leq 0.05$ and at $p \leq 0.01$ by the F test, respectively.

The Dickson Quality Index (DQI) diminished with increasing levels of electrical conductivity in the irrigation water (Figure 7A). Plants grown under a water salinity of 3.5 dS m^{-1} had a DQI of 0.12, representing a 53.84% reduction compared to those irrigated with an ECw of 0.3 dS m^{-1}. The DQI is an integrated morphological measure that, by correlating robustness (plant height and stem diameter) with the balance of phytomass distribution, is considered a reliable indicator of seedling quality for field transplantation (F. A. Oliveira et al., 2013). Therefore, despite the reduction in DQI with increasing salinity levels, water with an electrical conductivity of up to 0.3 dS m^{-1} can still be used to produce guava seedlings of acceptable quality for field transplantation, provided that the DQI remains above 0.28 (Dickson et al., 1960).

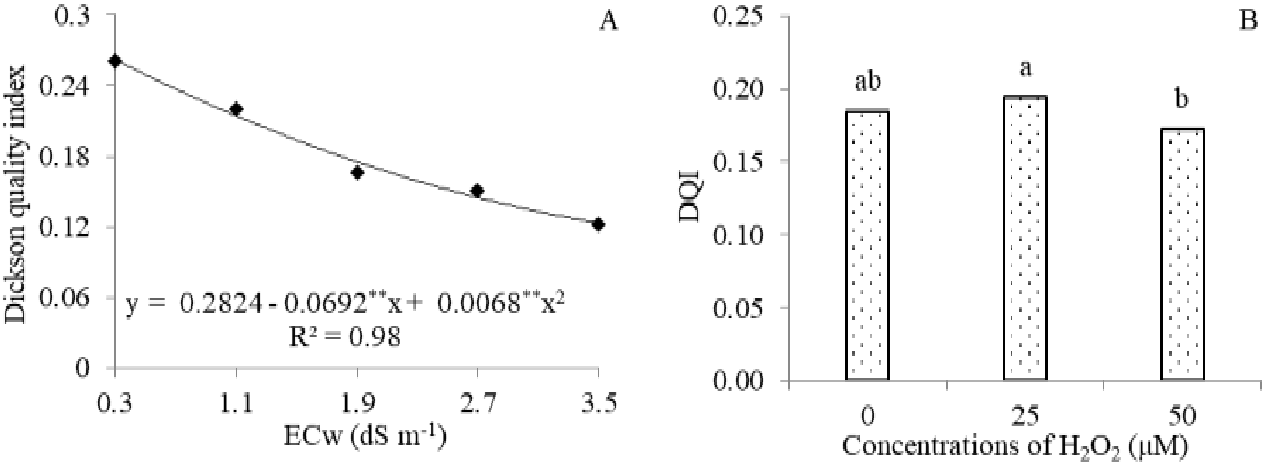

Figure 7. Dickson quality index of ‘Paluma’ guava seedlings as a function of water electrical conductivity levels (ECw - A) and hydrogen peroxide concentrations (B) at 110 days after sowing. *, ** - significant at $p \leq 0.05$ and at $p \leq 0.01$ by the F test, respectively.

The DQI was also influenced by H_2O_2 concentrations (Figure 7B), with the highest value observed at a concentration of 25 µM, yielding a DQI of 0.24, which represents an increase of 10.52% compared to plants under a H_2O_2concentration of 50 µM. However, it is noteworthy that even though the optimal DQI was achieved at the concentration of 25 µM H_2O_2, the guava seedlings did not reach a sufficient quality level (above 0.28) to be introduced into the field.

In a study conducted by J. T. A. Ferreira et al. (2023) on guava seedlings under salt stress conditions, a decrease of 9.78% in the DQI per unit increase in ECw was observed. In relative terms, there was a 40.32% reduction in the DQI between plants grown under an ECw of 4.3 dS m^{-1} and those irrigated with the lowest salinity level of 0.3 dS m^{-1}. However, regarding the effects of H_2O_2, no significant effects of the studied concentrations (0, 25, 50, and 75 µM) were observed.

Conclusions

Water salinity from 0.3 dS m^{-1} negatively affects the growth and development of 'Paluma' guava seedlings 110 days after sowing.

Hydrogen peroxide at a concentration of 25 μM increases the emergency speed index of 'Paluma' guava seedlings at 110 days after sowing.

The use of hydrogen peroxide, at a concentration of up to 50 μM, does not alleviate the adverse impacts of salt stress on 'Paluma' guava seedlings irrigated with water with an electrical conductivity of 3.5 dS m^{-1}.

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