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Scientific Article

Saline water irrigation and foliar application of H_2O_2 change ionic homeostasis of sour passion fruit

Irrigação com águas salinas e aplicação foliar de H_2O_2 altera a homeostase iônica do maracujazeiro-azedo

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ABSTRACT - Qualitative and quantitative scarcity of water sources is a reality in the Brazilian semi-arid region and restricts the expansion of irrigated areas in this region, where high levels of soluble salts are common. Thus, it is extremely important to seek strategies to enable the production of fruit crops such as sour passion fruit. In this context, the objective of this study was to evaluate the levels of NPK, Na^+ and Cl^- in leaf and stem tissues of sour passion fruit cv. BRS Rubi do Cerrado as a function of irrigation with saline water and exogenous application of hydrogen peroxide. The experiment was carried out in drainage lysimeters under greenhouse conditions in Campina Grande, PB, Brazil. The design was completely randomized in split plots, with five levels of electrical conductivity of water - ECw (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) considered plots and four concentrations of hydrogen peroxide – H_2O_2 (0, 15, 30 and 45 µM) considered subplots, with three repetitions. Sodium content in the leaves decreased when the H_2O_2 concentration of 45 µM was applied. N/P and N/Na ratios in the leaves of sour passion fruit cv. BRS Rubi do Cerrado decreased with the increase in irrigation water salinity from 2.76 and 2.03 dS m^{-1}, respectively. Chloride content in the leaves of sour passion fruit increased as a function of irrigation water salinity, regardless of H_2O_2 application.

Keywords: *Passiflora edulis Sims*. Fruit farming. Salt stress. Plant nutrition.

RESUMO - A escassez qualitativa e quantitativa das fontes hídrica é uma realidade no semiárido brasileiro e restringe a expansão das áreas irrigadas. Desta forma, é de suma importância buscar estratégias para viabilizar a produção de fruteiras como o maracujazeiro-azedo. Nesse sentido, objetivou-se com este estudo avaliar os efeitos da aplicação foliar de peróxido de hidrogênio na homeostase iônica do maracujazeiro-azedo cv. BRS Rubi do Cerrado sob irrigação com águas salinas. O experimento foi desenvolvido em lisímetros de drenagem sob condições de casa de vegetação em Campina Grande – PB. O delineamento foi inteiramente casualizado em parcelas subdivididas, sendo cinco níveis de condutividade elétrica da água - CEa (0,6, 1,2, 1,8, 2,4 e 3,0 dS m^{-1}) consideradas as parcelas e quatro concentrações de peróxido de hidrogênio – H_2O_2 (0, 15, 30 e 45 µM) as subparcelas, com três repetições. Os teores de sódio nas folhas reduziram nas plantas submetidas à aplicação de 45 µM de H_2O_2. As relações N/P e N/Na na folha do maracujazeiro-azedo cv. BRS Rubi do Cerrado reduziram com o aumento da salinidade da água de irrigação a partir de 2,76 e 2,03 dS m^{-1} respectivamente. Os teores de cloreto nas folhas do maracujazeiro-azedo aumentaram em função da salinidade da água de irrigação, independente da aplicação do peróxido de hidrogênio.

Palavras-chave: *Passiflora edulis Sims*. Fruticultura. Estresse salino. Nutrição vegetal.

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INTRODUCTION

Excess salts in water or soil cause complex changes in plant nutrition, including in sour passion fruit (*Passiflora edulis* Sims), which is characterized by sensitivity to salt stress. However, in regions with a semi-arid climate, the electrical conductivity of spring water used for irrigation varies between 0.3 and 3.0 dS m^{-1} depending on the time of year and the local geological composition (SOUZA et al., 2023).

The Northeast region of Brazil occupies a prominent position in passion fruit cultivation, with a production of 683,993 t, which represents 69.59% of all national production, and average yield of 14,785 t ha^{-1} with a planted area of 32,341 ha, and the largest producers are the states of Pernambuco (32,135 t), Alagoas (21,729 t) and Rio Grande do Norte (16,195 t) (IBGE, 2022). However, the high rates of evapotranspiration, young soils with low water storage capacity, great temporal and spatial variability in rainfall distribution, and high temperatures limit agricultural productivity in this region (BRITO et al., 2012; NOBRE et al., 2012).

The increase in the concentration of salts in irrigation water or in the soil solution causes osmotic stress in plants, acting mainly on the reduction of the osmotic potential of the soil solution and on the absorption of nutrients, such as potassium, causing an imbalance in the K^+/Na ratio (LIMA et al., 2023). Thus, it is necessary to search for strategies that minimize the effects of salt stress on plants. From this perspective, hydrogen peroxide (H_2O_2) stands out as an elicitor of the deleterious effects of saline water irrigation on plants due to its promising responses (LIMA et al., 2021; SILVA et al., 2021; VELOSO et al., 2022).

Dantas et al. (2022) evaluated the effect of nutrient solution salinity (2.1 to 3.6 dS m^{-1}) on zucchini cultivation in hydroponic system and under exogenous application of H_2O_2 (0 to 60 µM) and observed that plants under application of 20 µM of H_2O_2 in nutrient solution with electrical conductivity of 2.1 dS m^{-1} obtained higher total weight and basal diameter of fruits. Andrade et al. (2022), in a study with sour passion fruit under irrigation with saline water (0.7, 1.4, 2.1 and 2.8 dS m^{-1}) and foliar application of H_2O_2 (0, 20, 40 and 60 µM), concluded that the application of H_2O_2 at a concentration of 20 µM promoted the highest values for variable and maximum fluorescence and carotenoid content, constituting an alternative for acclimatization of passion fruit to salt stress.

Thus, the objective of this study was to evaluate the levels of NPK, Na and Cl^- in sour passion fruit plants cv. BRS Rubi do Cerrado, as a function of irrigation with saline water and exogenous application of H_2O_2.

MATERIAL AND METHODS

The experiment was conducted between May 2019 and January 2020 under conditions of arched greenhouse, 30 m long and 21 m wide, with ceiling height of 3.0 m and 150-micron low-density polyethylene cover, belonging to the Academic Unit of Agricultural Engineering – UAEAg, of the Federal University of Campina Grande – UFCG, Campina Grande, Paraíba, Brazil. Throughout the experimental period, the average maximum and minimum temperatures (33.5 and 30 ºC, respectively) were recorded daily at 9:00 a.m., using a digital thermometer (Figure 1).

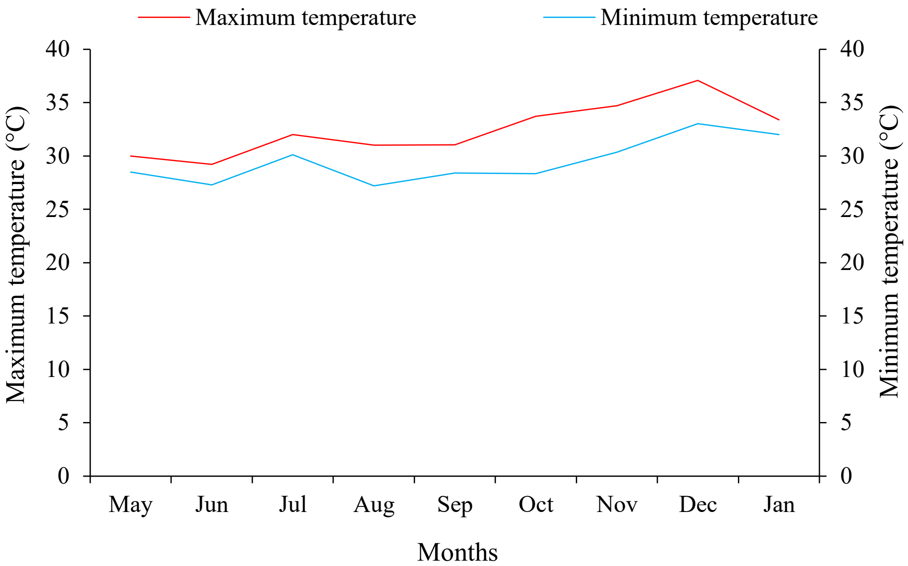

Figure 1. Daily maximum and minimum temperature data inside the greenhouse during the experimental period.

The treatments consisted of the combination of five levels of electrical conductivity of the irrigation water - ECw (0.6, 1.2, 1.8, 2.4 and 3.0 dS m^{-1}) and four different concentrations of hydrogen peroxide - H_2O_2 (0, 15, 30 and 40 µM), using a completely randomized design in a split-plot scheme, with ECw levels considered plots and H_2O_2 concentrations considered subplots, with three replicates. ECw levels and H_2O_2 concentrations were established based on a study conducted by Andrade et al. (2019).

Seeds of sour passion fruit cv. BRS Rubi do Cerrado were used in the experiment. Fruits of sour passion fruit cv. BRS Rubi do Cerrado are characterized by their predominantly red, purplish or yellowish skin, weight from 120 to 300 g (average of 170 g $fruit^{-1}$), with a rounded shape, soluble solids content of 13 to 15° Brix (average of 14° Brix), juice yield around 35%, greater resistance to transport, strong yellow pulp color (higher content of ascorbic acid), and resistance to diseases such as those caused by viruses and bacteria, as well as anthracnose and scab (EMBRAPA, 2012).

Seedlings were produced in plastic bags with capacity for 3 dm^3, filled with substrate in the proportion of 84% soil, 15% washed sand and 1% organic matter (earthworm humus). Substrate moisture content was raised to the maximum water holding capacity, and then 4 seeds per bag were sown at 3 cm depth.

The seedlings were irrigated daily, based on the weighing lysimetry principle. At 70 days after emergence, when the plants had tendrils, they were transplanted to the drainage lysimeters with a capacity for 250 L each (70 cm in height, bottom diameter of 57 cm and upper diameter of 57 cm). A hole was made at the base of the lysimeters and connected to a drain, and a non-woven geotextile (Bidim) was placed above each drain to avoid clogging by soil material. The end of each drain was connected to a plastic container to collect the drained water, and estimate water consumption of the plant by the balance of the volume applied in irrigation minus the volume drained, measured 24 h after irrigation.

The lysimeters were first filled with a 0.5 kg layer of crushed stone No. 0 followed by 250 kg of soil material classified as *Luvissolo crômico* (Alfisol) collected in the municipality of Alagoa Nova, PB. The soil was collected at 0-30 cm depth (A horizon), before starting the experiment, and its chemical and physical attributes were determined (Table 1) according to the methodology of Teixeira et al. (2017).

Table 1. Chemical and physical-hydraulic characteristics of the soil used in the experiment, before application of the treatments.

Chemical characteristics									
pH (H_2O) (1:2.5)	OM dag kg^{-1}	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$Al^{3+} + H^+$	ESP (%)	ECse (dS m^{-1})
			(cmol$_c$ kg^{-1})						
5.90	1.36	6.80	0.22	0.16	2.60	3.66	1.93	1.87	1.0

Physical-hydraulic characteristics									
Particle-size fraction (dag kg^{-1})			Textural class	Moisture (kPa)		AW	Total porosity %	BD	PD
Sand	Silt	Clay		33.42.	1519.5 dag kg^{-1}			(kg dm^{-3})	
732.9	142.1	125.0	SL	11.98	4.32	7.66	47.74	1.39	2.66

OM – Organic Matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 M KCl at pH 7.0; Na^+ and K^+ extracted with 1 M NH_4OAc at pH 7.0; Al^{3+} and H^+ extracted with 0.5 M CaOAc at pH 7.0; ESP – Exchangeable sodium percentage; ECse – Electrical conductivity of saturation extract; SL – Sandy Loam; AW – Available water; BD - Bulk density; PD - Particle density.

The levels of electrical conductivity of irrigation water were prepared so as to obtain an equivalent ratio of 7:2:1 of Na:Ca:Mg, from the salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, respectively, adjusting the concentrations of the available public-supply water to reflect the common proportion of salts found in the water bodies of the semi-arid region. Irrigation waters were prepared considering the relationship between ECw and the concentration of salts according to Richards (1954), as presented in Equation 1:

$$C \approx 640 \times ECw \quad (1)$$

Where:
C = Concentration of salts to be added (mg L^{-1});
ECw = Electrical conductivity of water (dS m^{-1}).

Irrigation with saline water started from 15 days after transplanting (DAT). Prior to this period, the plants were irrigated with water of lowest electrical conductivity (0.6 dS m^{-1}), and its chemical characteristics are presented in Table 2.

After transplanting, irrigation was carried out daily, manually, applying to each lysimeter the volume calculated based on the soil water balance, whose volume to be applied to the plants was determined by Equation 2:

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

Where:
VI = Volume of water to be used in the next irrigation event (mL);
Va = volume applied in the previous irrigation event (mL);
Vd = volume drained (mL); and
LF = leaching fraction of 0.15, applied every 15 days to reduce salt accumulation in the root zone of the crop.

Table 2. Chemical characteristics of the water with lowest electrical conductivity (0.6 dS m^{-1}) used in the experiment.

EC	pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	CO_3^-	HCO_3^-	SAR
dS m^{-1}	-				(mmol$_c$ L^{-1})				(mmol$_c$ L^{-1})$^{0.5}$
0.4	7.67	0.69	1.34	1.19	0.13	1.50	0.10	1.53	1.10

EC: electrical conductivity; CO_3^-: calcium carbonate; HCO_3^-: sodium bicarbonate; SAR: sodium adsorption ratio.

H_2O_2 concentrations were prepared in deionized water in each application event, due to its rapid degradation in the presence of light, and the volume used per treatment was quantified at the end of each application. During the vegetative stage until the beginning of flowering, the average volume of H_2O_2 solution used in each application was 63.75 mL. To avoid drift of the H_2O_2 solution, the plants of each treatment were isolated using plastic curtains.

H_2O_2 concentrations were applied by foliar spraying, at intervals of 15 days, starting at 15 days after irrigation with saline water and continuing until the flowering stage of the plants, using a knapsack sprayer equipped with an adjustable metal conical nozzle, with an opening of 1 cm, operating at a service pressure of 300 Psi and with a flow rate of 1.1 L min^{-1}.

Foliar applications were performed from 5:00 p.m., due to the lower incidence of light.

The spacing adopted was 2.20 m between rows and 1.50 m between plants, using the vertical trellis system with smooth wire n°14 installed inside the greenhouse, at 2.40 m height from the floor and 1.60 m from the lysimeter soil. When the plants reached 10 cm above the trellis, the apical bud was pruned to stimulate the growth of secondary branches, which were grown one to each side up to 1.10 m length, and a new pruning was performed to stimulate the growth of tertiary branches, which were pruned at 30 cm from the ground. After pruning, a Bordeaux mixture solution was applied to promote the healing of injuries and prevent diseases.

Basal fertilization was carried out according to the recommendation of São José (2000), with monthly application of 250 g of single superphosphate (18.9% P_2O_2) and 100 g of potassium chloride (60% K_2O) until the beginning of the flowering stage of the plants. After reaching this stage of development, nitrogen and potassium fertilization was carried out monthly, according to the methodology proposed by Santos (2001), using urea (45.9% N) and potassium chloride (60% K_2O) as sources of nitrogen and potassium, respectively.

A N/K ratio of 1/1, taking 10 g of nitrogen as a reference, was used in the crop formation stage and, from the beginning of flowering, the N dose was raised to 20 g and the K dose was raised to 30 g, increasing the N/K ratio of 1/1.5. Micronutrient fertilization was carried out according to EMBRAPA (2010); at intervals of 15 days, the plants were sprayed with a solution containing 2.5 g L^{-1} of commercial fertilizer with the following characteristics: Zn (0.5%); B (0.05%); Fe (0.5%); Mn (0.05%); Cu (0.5%) and Mo (0.02%).

At 240 DAT, at the end of flowering and beginning of production, stem and leaves of sour passion fruit were collected, packed and identified in paper bags and dried in a forced air circulation oven at 65 °C until reaching constant weight. Weighing was performed on a digital scale with accuracy of 0.05 g. The samples were ground by hand and then ground in a knife mill.

Contents of nutrients (Na, K, P, N, Cl) and the Na/K, N/Na and N/P ratios in the leaf and stem of sour passion fruit cv. BRS Rubi do Cerrado were determined following the methodology of Tedesco, Volkweiss and Bohnen (1985).

Shapiro-Wilk test was applied to the obtained data to check the assumption of normality. Then, they were subjected to analysis of variance using the F test at $p \leq 0.05$ and, when significant, linear and quadratic polynomial regression analysis was performed, using the statistical software SISVAR ESAL (FERREIRA, 2019). When there was heterogeneity in the data, exploratory analysis of the data was performed, with transformation to square root.

RESULTS AND DISCUSSION

There was a significant effect of the interaction (SL × H_2O_2) for all variables analyzed, except for nitrogen (N) and phosphorus (P) in the leaves. Nitrogen (N), phosphorus (P), potassium (K) and sodium (Na) contents in the leaves and stem of sour passion fruit cv. BRS Rubi do Cerrado were significantly affected by the salinity of irrigation water. Regarding the concentrations of hydrogen peroxide (H_2O_2), except for N_{leaf}, P_{leaf} and K_{leaf}, there was a significant effect on all nutrients evaluated in leaf and stem tissues (Table 3).

Table 3. Summary of the analysis of variance for leaf and stem nitrogen (N), phosphorus (P), potassium (K), sodium (Na) and chloride (Cl) contents of sour passion fruit cv. BRS Rubi do Cerrado under saline water irrigation and exogenous application of hydrogen peroxide (H_2O_2) at 240 days after transplanting (DAT).

Source of variation	DF	Mean squares							
		N_{leaf}	N_{stem}	P_{leaf}	P_{stem}	K_{leaf}	K_{stem}	Na_{leaf}	Na_{stem}
Salinity levels (SL)	4	0.15^{*}	7.52^{**}	2.39^{**}	14.97^{**}	6.52^{*}	9.57^{**}	$165395,73^{**}$	$104960,2^{**}$
Linear Regression	1	0.32^{**}	21.71^{**}	7.97^{**}	50.31^{**}	2.32^{**}	30.55^{**}	636241.59^{**}	402174.79^{**}
Quadratic Regression	1	0.99^{**}	7.67^{**}	0.88^{*}	$8\times10^{-4**}$	0.16^{**}	0.61^{**}	19735.15^{**}	152.73^{**}
Residual 1	8	0.04	0.295	0.12	0.07	1.30	0.23	180.30	632.28
Hydrogen peroxide (H_2O_2)	3	0.07^{ns}	8.44^{**}	0.09^{ns}	4.03^{**}	1.85^{ns}	2.04^{**}	2789.54^{**}	8816.89^{**}
Linear Regression	1	0.11^{ns}	9.57^{**}	0.19^{ns}	0.19^{ns}	0.76^{ns}	3.00^{**}	2975.25^{**}	1692.13^{*}
Quadratic Regression	1	0.03^{ns}	12.65^{**}	0.06^{ns}	0.07^{ns}	0.85	0.22^{ns}	75069.99^{**}	2615.82^{**}
Interaction (SL × H_2O_2)	12	0.07^{ns}	4.28^{**}	0.11^{ns}	1.81^{**}	12.61^{**}	6.01^{**}	4289.31^{**}	2487.40^{**}
Residual 2	30	0.41	0.42	0.10	0.22	0.85	0.26	178.88	379.65
CV 1 (%)		2.51	6.28	17.01	9.23	11.00	9.23	4.50	9.51
CV 2 (%)		2.41	7.53	15.17	15.91	8.94	9.87	4.40	7.37

ns, **, * not significant, significant at $p \leq 0.01$ and $p \leq 0.05$; DF – Degrees of freedom; CV – Coefficient of variation.

Regarding the effect of irrigation water salinity on nitrogen (N) content in the leaves of sour passion fruit cv. BRS Rubi do Cerrado, a reduction of 1.9% (0.16 g kg^{-1}) was observed when comparing plants irrigated with the lowest salinity level (0.6 dS m^{-1}) with those cultivated with ECw of 3.0 dS m^{-1} (Figure 2A). Nitrogen contents in the stem (Figure 2B) were significantly affected by the interaction between the factors (SL × H_2O_2), with the highest N_{stem} content (7.69 g kg^{-1}) obtained in plants subjected to H_2O_2 concentration of 0 µM and irrigated with water of 1.21 dS m^{-1}, while plants that received the H_2O_2 concentration of 45 µM had highest N_{stem} content (8.12 g kg^{-1}) under irrigation with 1.03 dS m^{-1} water. In relative terms, a reduction of 27.26% (3.65 g kg^{-1}) was observed in N_{stem} contents with the increase in H_2O_2 concentration from 0 to 45 µM at the highest salinity level (3.0 dS m^{-1}).

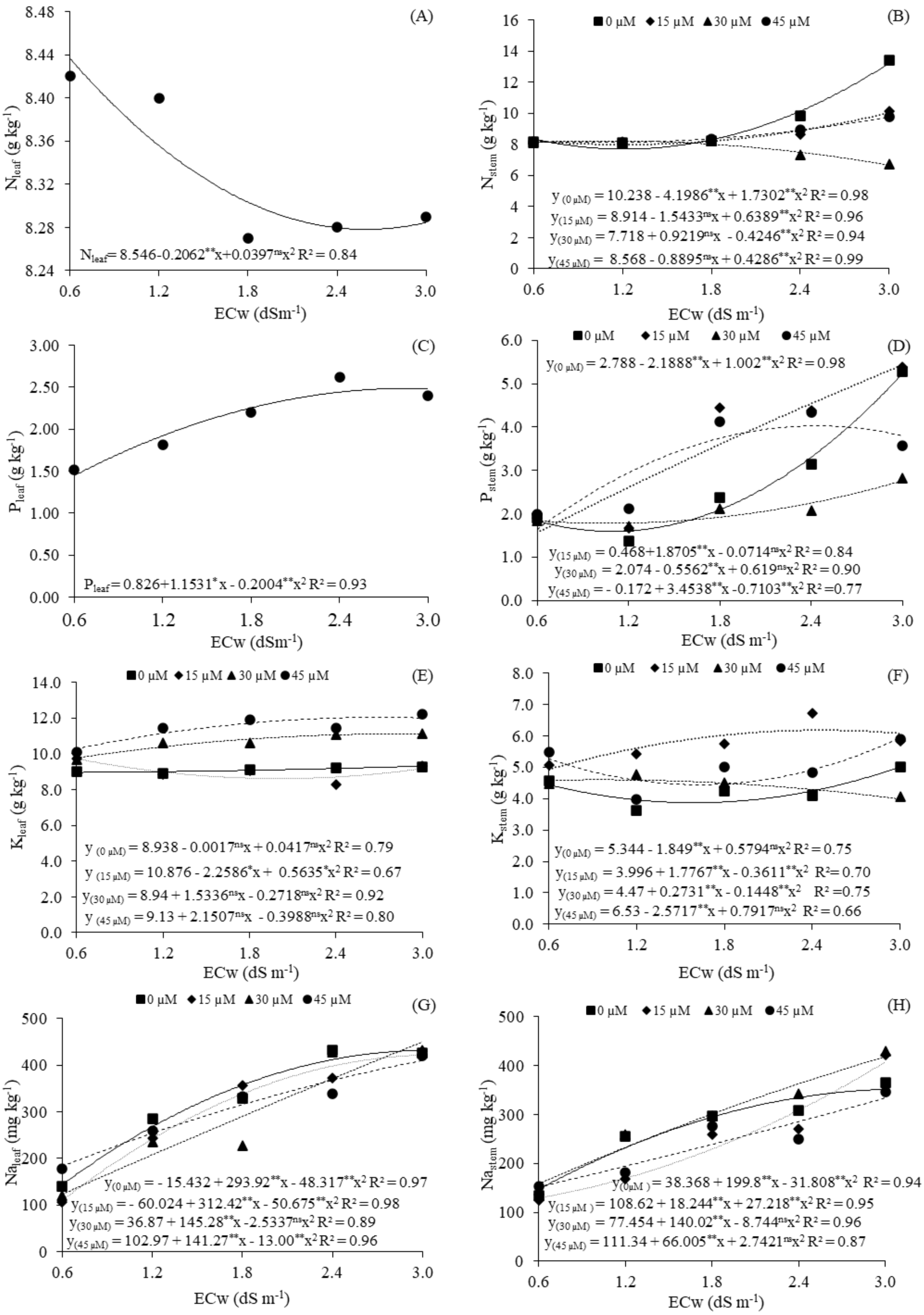

Figure 2. Contents of nitrogen - N_{leaf} (A) and N_{stem} (B), phosphorus - P_{leaf} (C) and P_{stem} (D), potassium - K_{leaf} (E) and K_{stem} (F), and sodium - Na_{leaf} (G) and Na_{stem} (H) of sour passion fruit cv. BRS Rubi do Cerrado as a function of irrigation water salinity - ECw and exogenous application of H_2O_2 at 240 days after transplanting.

According to Fageria (2001), the absorption and transport of NO^{3-} (nitrogen) are limited under salinity conditions due to the antagonistic effect with Cl^-.

Regarding the accumulation of P in the leaves, a linear and increasing effect was observed as ECw increased, with maximum value obtained under irrigation with an estimated ECw of 0.26 dS m^{-1}, which promoted an accumulation of 1.103 g kg^{-1}. In relative terms, an increase of 41.74% (1.03 g kg^{-1}) was observed (Figure 2C) when comparing the P contents in plants irrigated with the highest salinity level (3.0 dS m^{-1}) to those irrigated with ECw of 0.6 dS m^{-1}. In the stem (Figure 2D), the effect on P contents was similar to that observed in the leaves (Figure 2C), which increased as irrigation water salinity increased. The regression equation showed that the maximum estimated value for P (12.71 g kg^{-1}) was reached in plants cultivated under irrigation using water with electrical conductivity of 13.09 dS m^{-1} and 15 µM of H_2O_2.

When comparing the values achieved in plants irrigated with the highest (3.0 dS m^{-1}) and lowest (0.6 dS m^{-1}) salinity levels, increments in P_{stem} contents of 63.94% (3.37 g kg^{-1}), 64.68% (3.48 g kg^{-1}), 34.75% (0.98 g kg^{-1}) and 43.97% (1.57 g kg^{-1}) were observed in plants cultivated under H_2O_2 concentrations of 0, 15, 30, and 45 µM, respectively.

This effect may be related to the ability of plants to adjust osmotically through the accumulation of carbohydrates or organic solutes (sugars) in order to protect the cells from abiotic stress, since the presence of P in the plant under salt stress conditions induces genes encoding the protein kinase, which responds to both ionic and nonionic (exudate formation) reactions (FU et al., 2016).

For the K_{leaf} contents (Figure 2E), the maximum estimated values of 8.93, 8.61, 11.10 and 12.02 g kg^{-1} were obtained in plants subjected to H_2O_2 concentrations of 0, 15, 30 and 45 µM under irrigation using water with electrical conductivity of 0.02, 2.0, 2.82 and 2.69 dS m^{-1}, respectively. It is worth pointing out that, as the H_2O_2 concentration increased, regardless of the salinity level, there was an increase in the K content in the leaves of sour passion fruit cv. BRS Rubi do Cerrado.

K content in the stem (Figure 2F) followed a trend similar to that observed in the leaves; as irrigation water salinity and H_2O_2 concentration increased, there was an increase in the accumulation of this element, and the highest content (6.17 g kg^{-1}) was observed under electrical conductivity of 2.45 dS m^{-1} and application of 15 µM (Figure 2F). In relative terms, there were increments of 8.98% (0.45 g kg^{-1}) and 6.94% (0.41 g kg^{-1}) in K contents in plants irrigated with the lowest salinity level (0.6 dS m^{-1}) compared to those cultivated under the highest salinity level (3.0 dS m^{-1}) and H_2O_2 concentrations of 0 and 45 µM, respectively.

The increase in K contents in both leaves and stem of sour passion fruit can be considered a mechanism of tolerance to salt stress, since the K ion can act as an osmoregulator in order to maintain the turgor pressure and the relative water content in the plant (GENG et al., 2016).

Leaf Na contents were affected by the interaction between irrigation water salinity and H_2O_2 concentration (Figure 2G). The regression equation showed that, regardless of the H_2O_2 concentration applied, there was an increase in Na content in the leaves of sour passion fruit cv. BRS Rubi do Cerrado with the increase in irrigation water salinity, and the maximum values were 431.53, 421.50, 2119.42 and 486.76 mg kg^{-1} in plants irrigated using water with electrical conductivity of 3.04, 3.08, 28.66 and 5.43 dS m^{-1}, respectively.

The increase in irrigation water salinity from 0.6 to 3.0 dS m^{-1} promoted a quadratic increase in the leaf Na contents (Figure 2G), with the maximum estimated values of 431.09, 420.7, 122.4 and 145.09 mg kg^{-1} obtained in plants subjected to foliar application of 0, 15, 30 and 45µM of H_2O_2 and ECw of 3.04, 3.08, 28.71 and 0.83 dS m^{-1}, respectively. In relative terms, there were increments in Na_{leaf} contents of 67.29% (286.84 mg kg^{-1}), 75.44% (324.89 mg kg^{-1}), 72.14% (311.93 mg kg^{-1}) and 57.76% (243.08 mg kg^{-1}) in plants cultivated under ECw of 3.0 dS m^{-1} compared to those that received the lowest level of water salinity (0.6 dS m^{-1}) as a function of H_2O_2 concentrations. This increase in leaf Na contents may be related to the excess of the element in the cells, thus increasing oxidative stress due to the increase in the production of reactive oxygen species (ROS), which causes damage to proteins, lipids and nucleic acids (AMIN et al., 2021).

As observed for N_{leaf} contents (Figure 2A), the increase in H_2O_2 concentrations increased Na_{stem} contents in the sour passion fruit plants (Figure 2H), and the maximum estimated values of 351.93, 117.87, 637.96 and 1051.03 mg kg^{-1} were obtained under irrigation with ECw of 3.14, 0.34, 8.01 and 12.04 dS m^{-1} at H_2O_2 concentrations of 0, 15, 30 and 45 µM, respectively. When comparing the Na contents in the stem of sour passion fruit plants irrigated with ECw of 3.0 dS m^{-1} between H_2O_2 concentrations of 0 µM and 45 µM, a reduction of 5.09% (18.56 mg kg^{-1}) was observed.

H_2O_2 probably acted as a signaling molecule in the mitigation of salt stress, which, despite being rapidly eliminated by other antioxidative enzymes, such as superoxide dismutase, has a long half-life and its chemical characteristics facilitate its displacement within cells, stimulating the plant to produce antioxidative enzymes in order to reach ionic homeostasis (ČERNÝ et al., 2018).

There was a significant effect of the interaction between the factors (SL × H_2O_2) on all variables analyzed, except for the N/P ratio in the leaves and stem (Table 4). The chloride contents and the Na/K, N/Na and N/P ratios in the leaves and stem of sour passion fruit cv. BRS Rubi do Cerrado, at 240 days after transplanting, were significantly affected by the salinity of irrigation water. Exogenous application of H_2O_2 also significantly influenced the chloride contents in the leaves (Cl_{leaf}) and in the stem (Cl_{stem}) and all the ratios, except the N/P ratio in the leaves.

Table 4. Summary of the analysis of variance for chloride (Cl) contents and Na/K, N/Na and N/P ratios in the leaves and stem of sour passion fruit cv. BRS Rubi do Cerrado under saline water irrigation and exogenous application of hydrogen peroxide (H_2O_2) at 240 days after transplanting.

Source of variation	DF	Mean squares							
		Cl_{leaf}	Cl_{stem}	Na/K_{leaf}	Na/K_{stem}	N/Na_{leaf}	N/Na_{stem}	N/P_{leaf}	N/P_{stem}
Salinity levels (SL)	4	1875.5^{**}	188.8^{**}	1557.2^{**}	1958.1^{**}	$4x10^{-2**}$	$21x10^{-2**}$	11.6^{**}	16.9^{**}
Linear Regression	1	6421.6^{**}	628.9^{**}	5551^{**}	5547.8^{**}	$13x10^{-3**}$	$7x10^{-2**}$	39.6^{**}	47.1^{**}
Quadratic Regression	1	261.5^{**}	16.9^{**}	61.2^{**}	415.3^{**}	0.09^{**}	$1x10^{-2**}$	5.4^{**}	1.2^{ns}
Residual 1	8	30.5	7.7	13.6	44.4	$9x10^{-5}$	$5x10^{-4}$	0.3	0.3
Hydrogen peroxide (H_2O_2)	3	94.6^{**}	39.4^{**}	121.7^{**}	1040.9^{**}	$14x10^{-3**}$	$3x10^{-3**}$	0.04^{ns}	2.8^{ns}
Linear Regression	1	2.6^{**}	0.03^{ns}	78.9^{*}	618.6^{**}	$1x10^{-5ns}$	$43x10^{-4ns}$	0.9^{ns}	4.4^{**}
Quadratic Regression	1	229.7^{**}	49.2^{**}	100.3^{**}	66.6^{ns}	$44x10^{-3**}$	$1.3x10^{-3*}$	0.6^{ns}	0.1^{ns}
Interaction (SL × H_2O_2)	12	765.9^{**}	75.9^{**}	90.2^{**}	601.1^{**}	$15x10^{-3**}$	$98x10^{-6**}$	0.44^{ns}	0.9^{ns}
Residual 2	30	18.5	2.7	4.2	48.1	$4x10^{-5}$	$26x10^{-4}$	0.28	0.6
CV 1 (%)		11.09	11.91	12.29	12.72	8.79	19.03	12.27	16.63
CV 2 (%)		8.64	7.11	12.53	13.24	5.57	13.86	12.58	23.37

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

The H_2O_2 concentrations did not attenuate the effect of irrigation water salinity on the chloride contents in the leaves of sour passion fruit, regardless of the H_2O_2 concentration. According to the regression equations (Figure 3A), the maximum value for leaf chloride contents (14.19 g kg^{-1}) was obtained in plants that did not receive H_2O_2 application (0 µM) and were subjected to water salinity of 0.99 dS m^{-1}, and values of 65.1g kg^{-1}, 73.4g kg^{-1} and 57.20 g kg^{-1} were obtained under H_2O_2 concentrations of 15, 30 and 45 µM and ECw of 2.25, 2.19 and 1.69 dS m^{-1}, respectively.

In relative terms, there was an increase in Cl content of 70.44% (53.44 g kg^{-1}) with the increase in irrigation water salinity from 0.6 to 3.0 dS m^{-1}. A similar effect was observed in plants that were sprayed with the H_2O_2 concentrations of 15 and 30 µM, with increments of 47.47% (29.65 g kg^{-1}) and 48.06% (34.11 g kg^{-1}) when the electrical conductivity of irrigation water increased from 0.6 to 3.0 dS m^{-1} (Figure 3A).

In the stem, the Cl contents increased quadratically with the increase in the levels of electrical conductivity of irrigation water, regardless of the H_2O_2 concentration (Figure 3B). According to the regression equations, the maximum Cl accumulation in plants that did not receive H_2O_2 was 28.60 g kg^{-1}, obtained under an estimated ECw of 1.64 dS m^{-1}. On the other hand, at H_2O_2 concentration of 45 µM, the maximum accumulation (28.17 g kg^{-1}) was obtained in plants cultivated under an estimated water salinity of 3.07 dS m^{-1}. According to Hasegawa (2013), the mechanisms associated with the exclusion of toxic ions such as Cl^- depend both on the absorption selectivity of the root system and on the resistance of these ions to the transfer from the roots to the leaves, so as to maintain adequate levels of ionic concentration in the leaves. It can also be inferred that part of these salts absorbed by the plants were redistributed to other organs, because the tolerance of plants under salt stress conditions may be associated with mechanisms of retention of toxic ions in the roots, which limits their accumulation in quantities capable of causing damage to the photosynthetic tissue.

The interaction between irrigation water salinity and H_2O_2 application had a significant effect on the Na/K ratio of sour passion fruit cv. BRS Rubi do Cerrado. For plants that received H_2O_2 at a concentration of 45 µM, a Na/K_{leaf} ratio of 37.41 mg g^{-1} was observed under irrigation water salinity of 2.48 dS m^{-1}. It can be observed that, as irrigation water salinity increased, regardless of the H_2O_2 concentration applied, there was an increase in this ratio, except for the H_2O_2 concentration of 45 µM at salinity of 2.4 dS m^{-1} (Figure 3C).

The Na/K ratio in the stem increased as a function of the increase in irrigation water salinity and H_2O_2 concentration, differently from what was observed in the leaves, with maximum value of 69.05 obtained under ECw of 1.61 dS m^{-1} and H_2O_2 concentration of 0 µM. On the other hand, when the H_2O_2 concentration of 45 µM was applied, this value was 62.11 under water salinity of 2.50 dS m^{-1} (Figure 2D). In relative terms, it was found that, regardless of the H_2O_2 concentration applied, as the irrigation water salinity increased from 0.6 to 3.0 dS m^{-1}, there was an increase in the sodium ion content compared to the potassium ion, except for the concentration of 15 µM, which led to a reduction of 1.68% (0.87) in the Na/K ratio (Figure 3D).

This effect is possibly related to high-affinity potassium transporters (HKT), which are highly selective, and the intrinsic characteristics of H_2O_2, which can act in the modulation of plant defense responses to salt stress, due to electrochemical factors that allow it to cross membranes and spread between cell compartments, which facilitates its signaling function (SILVA et al., 2020).

N/Na_{leaf} ratio was significantly affected by the interaction between irrigation water salinity and exogenous application of H_2O_2. The regression equation (Figure 3E) showed that the highest leaf N/Na ratio (0.04) was observed when irrigation was performed with water of 2.03 dS m^{-1} without H_2O_2 application, whereas with the application of 45 µM H_2O_2 a ratio of 0.02 was observed under ECw of 2.77 dS m^{-1}. There was a reduction in the N/Na ratio with the increase in irrigation water salinity at all H_2O_2 concentrations (Figure 3E). In comparative terms, there were reductions in the N/Na ratio of 61.66% (0.037) when the crop was not exposed to H_2O_2 and 59.18% (0.029) when the H_2O_2 concentration of 45 µM was applied between the highest (3.0 dS m^{-1}) and lowest (0.6 dS m^{-1}) salinity level.

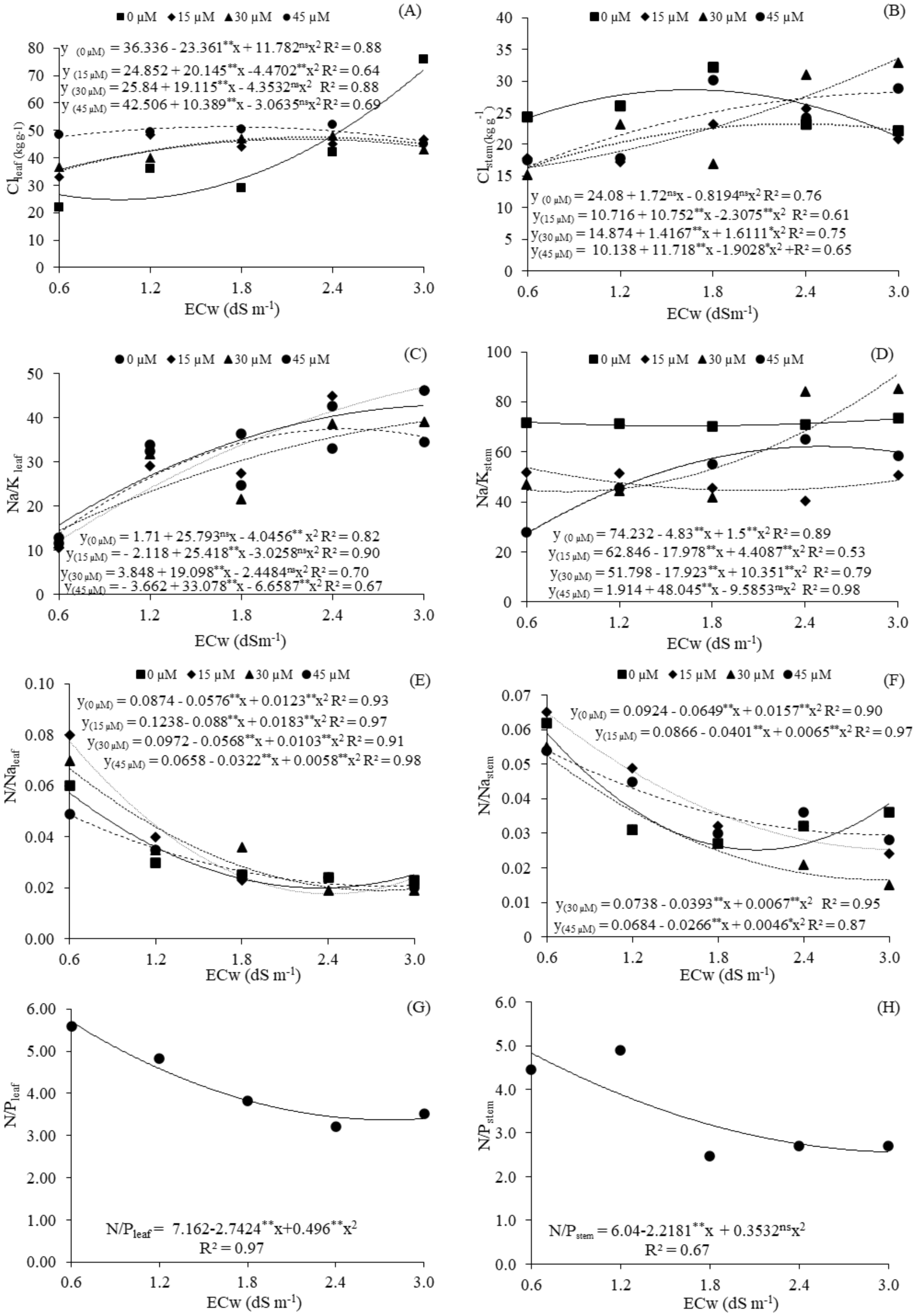

Figure 3. Contents of chloride - Cl_{leaf} (A and B), Na/K_{leaf} ratio (C and D) and N/Na_{leaf} (E and F) in sour passion fruit plants cv. BRS Rubi do Cerrado, as a function of the interaction between water salinity levels – ECw and hydrogen peroxide concentrations and N/P_{leaf} ratio (G and H) as a function of ECw levels, at 240 days after transplanting.

A similar effect was observed for the N/Na ratio in the stem of sour passion fruit cv. BRS Rubi do Cerrado (Figure 3F), with the highest value (0.029) in plants that received water of 2.89 dS m^{-1} at a H_2O_2 concentration of 45 µM, whereas when the plants were not exposed to H_2O_2 (0 µM), an N/Na ratio of 0.025 was observed under irrigation water salinity of 2.06 dS m^{-1}.

In comparative terms, the increase in irrigation water salinity significantly reduced the N/Na ratio regardless of the H_2O_2 concentration, with decreases of 41.93% (0.026), 66.13% (0.041), 72.72% (0.04) and 48.15% (0.026) when comparing plants that received the highest (3.0 dS m^{-1}) and the lowest (0.6 dS m^{-1}) salinity levels with H_2O_2 concentrations of 0, 15, 30 and 45 µM, respectively. Possibly, this reduction in nitrogen contents compared to sodium contents was due to competition between nitrate ions (NO_3^-) and Na^+ ions, since the accumulation of Na in the soil solution reduces N absorption, which probably favored an alteration in the ionic balance, thus promoting the lowest accumulation of this anion in the leaf and stem tissues of the plant (LIMA et al., 2015).

Freire et al. (2020) investigated the cultivation of two species of passion fruit (yellow and purple) under saline conditions (0.5 and 3.5 dS m^{-1}) and found that the leaf N content was affected by irrigation water salinity, showing a deficit (19.7 g kg^{-1}).

H_2O_2 is a ROS, considered as a byproduct of aerobic and photosynthetic metabolism and, at concentrations compatible with cellular redox homeostasis, is a component of several signaling pathways. However, excess ROS causes oxidative damage to proteins, lipids and nucleic acids, characterizing secondary oxidative stress (VELOSO et al., 2022).

The N/P ratio in the leaves decreased with the increase in irrigation water salinity, and its maximum value of 7.16 was reached in plants irrigated with water of 0.6 dS m^{-1}. On the other hand, the lowest N/P ratio (3.37) was obtained in plants irrigated with ECw of 2.76 dS m^{-1} (Figure 3G). In the stem (Figure 3H), the highest ratio (6.04) was observed under salinity level of 0.6 dS m^{-1}. It is important that the N/P ratio is in balance, since each macronutrient plays a fundamental role in plant nutrition, such as nitrogen and phosphorus, which are components that integrate proteins that build cellular materials and plant tissues, hence being vital for plant growth and development (ASHRAF et al., 2018).

CONCLUSIONS

Sodium contents in the leaves and stem of sour passion fruit cv. BRS Rubi do Cerrado increase regardless of the application of hydrogen peroxide. Hydrogen peroxide at a concentration of 30 µM alleviates salt stress effects on potassium and sodium contents in the leaves and stem of sour passion fruit cv. BRS Rubi do Cerrado cultivated under water salinity of 3.0 dS m^{-1}. N/P and N/Na_{leaf} ratios decrease with the increase in irrigation water salinity in sour passion fruit cv. BRS Rubi do Cerrado.

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