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Research article

Production and postharvest quality of yellow passion fruit cultivated with saline water and hydrogen peroxide

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Abstract: The present study aimed to evaluate the production and postharvest quality of yellow passion fruit, cultivated under different levels of irrigation water salinity and exogenous application of hydrogen peroxide. At low concentrations, hydrogen peroxide may favor plant acclimatization when subjected to saline stress conditions due to the activation of defense mechanisms. The experiment was conducted in greenhouse in the municipality of Campina Grande-PB, Brazil, using drainage lysimeters filled with sandy loam Entisol. The experimental design was randomized blocks, with 4 × 4 factorial arrangement with three replicates, consisting of four levels of irrigation water electrical conductivity—ECw (0.7, 1.4, 2.1 and 2.8 dS m^{-1}) and four concentrations of hydrogen peroxide—H_2O_2 (0, 20, 40 and 60 μM). The different concentrations of H_2O_2 were applied by soaking the seeds for a 24-h period before sowing and spraying the leaves on the adaxial and abaxial sides. At the end of the cycle (205 days after transplanting-DAT), passion fruit production was evaluated by determining the number of fruits per plant, mean fruit weight and total fruit weight. Postharvest quality was determined by physical characterization of fruit (equatorial and polar diameters and rind and pulp thicknesses), hydrogen potential in the pulp, titratable acidity and ascorbic acid. Increasing levels of irrigation water salinity negatively affected the production and physical and chemical quality of passion fruits. Number and total weight of fruits per plant were the most compromised variables. There was significant interaction between irrigation water salinity levels and H_2O_2 concentrations on fruits' polar diameter, at 205 days after transplanting. Foliar application at estimated concentration of 27.5 and 41.5 µM H_2O_2 led to the highest values of total titratable acidity and vitamin C, respectively, at 205 DAT. Water salinity above 0.7 dS m^{-1} resulted in changes in the physico-chemical characteristics of passion fruit. Peroxide concentrations up to 60 µM did not mitigate the deleterious effects of salt stress on passion fruit yield and quality in the first crop cycle.

Keywords: *Passiflora edulis f. Flavicarpa;* reactive oxygen species; acclimation; salt stress; semi-arid

Abbreviations: DAT: Days after transplanting; TNF: Total number of fruits per plant; MFW: Mean fruit weight; TFW: Total fruit weight; FPD: Fruit polar diameter; FED: Fruit equatorial diameter; FRT: Fruit rind thickness; FPT: Fruit pulp thickness; pH: Hydrogen potential; TTA: Total titratable acidity; VIT C: Vitamin C content

1. Introduction

Yellow passion fruit (*Passiflora edulis* Sims f. *Flavicarpa* Degener) stands out as one of the most important fruit crops representing the fruit production chain at the levels of small and medium producers [1]. It is mainly cultivated in tropical countries, responsible for approximately 90% of the world production. According to [2], the full use of this fruit, using its pulp for fresh consumption and industrial purposes, its rind as feed and organic fertilizer, and seeds for oil extraction, contributes for yellow passion fruit to have great economic importance.

Brazilian passion fruit production has gained great economic expression just over 25 years, initially through the incentives for agroindustry and then through the increasing demand in fresh fruit market [3]. Brazil is the largest producer and consumer of this fruit in the world [4]. Among the producing regions, the Northeast region is the most expressive, but the high salinity of soils and water sources in in most of its cultivated areas has affected passion fruit production under conventional management [5].

In the semi-arid region of Northeast Brazil, the water supply to the soil comes from scarce and irregular rainfalls and/or supplementary irrigations, which are combined to a strong evaporation demand, imposing the use of water resources with restrictive quality to agricultural production [6]. In this region, yellow passion fruit management depends on irrigation, in many cases carried out using water with high salt contents, which may induce physiological modifications and affect plant growth and development [7].

According to [8,9], the problems caused by salt stress on plants result in alterations in osmotic potential, ionic toxicity and nutritional imbalance, causing reduction in their growth and development, consequently bringing serious losses to the agricultural activity. For yellow passion fruit, negative effects due to irrigation water of different levels of salinity have been reported on fruit production [10], water consumption [11] and on external and internal qualitative attributes of fruits [12]. Therefore, it is very important to search for alternatives which attenuate the effects of salt stress on yellow passion fruit plants, favoring the planting of orchards in areas with problems of salts in water and/or soil.

One of the alternatives that can contribute to minimizing salinity effects on plants is acclimation, which according to [13] consists in previous exposure to a certain type of stress, which causes metabolic changes responsible for increasing plant resistance to a new exposure to the stress. The use of hydrogen peroxide (H_2O_2) at low concentrations may favor plant acclimation to adverse conditions of salt stress. Several studies have reported the efficiency of low H_2O_2 concentrations, for instance [14] in the initial growth of corn, in the pre-treatment of corn plantlets [15], and in the pre-treatment of wheat seeds [16].

In research on saline stress and effect of exogenous application of H_2O_2 on the photosynthetic parameters of soursop, [17] found that the application of H_2O_2 at 25 and 50 µM concentrations mitigated the deleterious effects of water salinity on stomatal conductance, CO_2 assimilation and chlorophyll *a* content, the 25 µM concentration being the most efficient. Also, the effect of saline stress on chlorophyll *b* and carotenoids content of soursop cv. Morada Nova was alleviated when H_2O_2 was applied at a concentration of 25 µM.

For yellow passion fruit crop, studies addressing the use of H_2O_2 concentrations are scarce in the literature, especially in flowering and fruiting stages and during postharvest. Therefore, due to the socioeconomic relevance of this crop in the cultivated areas of the country and the losses caused by salt stress, especially in the semi-arid region of Northeast Brazil, it becomes essential to create viable alternatives that contribute to its cultivation under these conditions. In this context, the present study aimed to evaluate the effect of exogenous application of H_2O_2 on the production and postharvest quality of yellow passion fruit irrigated with saline water.

2. Material and methods

The study was conducted in drainage lysimeters under greenhouse conditions at the Center of Technology and Natural Resources of the Federal University of Campina Grande (CTRN/UFCG), located in the municipality of Campina Grande, PB, Brazil, situated by the local geographic coordinates 7°15’18” S, 35°52’28” W and mean altitude of 550 m.

The experimental design was randomized blocks in a 4 × 4 factorial arrangement, and treatments resulted from the combination of two factors, which were four levels of irrigation water electrical conductivity-ECw (0.7, 1.4, 2.1 and 2.8 dS m^{-1}) and four H_2O_2 concentrations (0, 20, 40 and 60 µM), with three replicates, totaling 48 experimental units. The different levels of water salinity (0.7, 1.4, 2.1 and 2.8 dS m^{-1}) were prepared using chloride salts in such a way to have an equivalent proportion of 7:2:1 relative to Na:Ca:Mg, respectively.

Irrigation solutions were prepared considering the relationship between ECw and the concentration of salts (10 * ECw dS m^{-1} = $mmol_c$ L^{-1}), according to [18]. The choice of the electrical conductivity levels mentioned was based on the threshold salinity of the crop, where the initial value of 0.7 dS m^{-1} was chosen, close to the maximum tolerated by the crop and three levels above it (1.4, 2.1 and 2.8 dS m^{-1}), according to [19], the yellow passion fruit is considered sensitive to salinity, i.e., it has a threshold salinity of only 1.3 dS m^{-1} for the electrical conductivity of the soil saturation extract which corresponds to water salinity of a maximum of 0.9 dS m^{-1} in terms of electrical conductivity.

After preparation and ECw calibration, the solutions were stored in 200-L plastic pots, one for each ECw level, properly protected to avoid evaporation and contamination with materials that could compromise quality. Treatment with H_2O_2 concentrations was performed by soaking the seeds prior to sowing and by spraying (on average 167 mL of H_2O_2 solution per plant) on the adaxial and abaxial sides of leaves of seedlings, at 15-day intervals until the flowering stage (when each plot had at least one open flower) using a backpack sprayer. The choice of H_2O_2 concentrations was based on the earlier study conducted by [17]. The hydrogen peroxide used in this study was of Neon brand, 35% pure, with specific density of 1.12 kg dm^{-3} and molecular weight of 34.01. Initially a 1 M solution of

H_2O_2 (30.5 mL L^{-1}) was prepared. With this solution further dilutions were made to prepare the other solutions of desired concentrations.

The experiment used seeds of the passion fruit (*Passiflora edulis* Sims) variety traditionally cultivated in the municipality of Nova Floresta–PB, popularly known as *Guinezinho,* due to the spots on the rind similar to those existing on the feathers of a bird locally known as 'galinha Guiné' (Helmeted guineafowl-*Numida meleagris*) [20]. These seeds came from a commercial orchard, obtained from plants subjected to mass selection in the municipality of Nova Floresta–PB, with standardization based on vigor and health.

To obtain the seedlings, 4 seeds were planted in pots (Citropote®) with capacity for 6 dm^3, filled with substrate, composed of a mixture of 84% soil, 15% washed sand and 1% organic compost (earthworm humus) up to 5.6 dm^3. After emergence, seedlings were thinned to leave only one plant per pot (the one with highest physiological vigor) when they were 10 cm tall. Irrigation was carried out with the respective saline solutions, from sowing, whereas the different H_2O_2 concentrations were applied by soaking the seeds for a 24-h prior to sowing and by spraying the leaves on the adaxial and abaxial sides, from the seedling production period.

At 65 days after sowing, when the main stem was approximately 35 cm long, the plants were transplanted to 100-L pots adapted as drainage lysimeters filled with a 0.5-kg layer of crushed stone, followed by 100 kg of a sandy loam Entisol (0–20 cm depth), properly pounded to break up clods. The soil was collected from the rural area of the municipality of Lagoa Seca, PB, whose chemical and physical characteristics (Table 1) were determined according to the methodology of [21].

Table 1. Physical and chemical characteristics of the soil used in the experiment, before applying the treatments.

Chemical characteristics									
pH (H_2O)	OM	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+} + H^+	ESP	EC_{se}
(1:2.5)	dag kg^{-1}	(mg kg^{-1})	($cmol_c$ kg^{-1})					(%)	(dS m^{-1})
5.90	1.36	6.8	0.22	0.16	2.60	3.66	1.93	1.87	1.0
Physical characteristics									
Size fraction (g kg^{-1})			Textural class	Water content (kPa)*		AW	Total porosity (m^3 m^{-3})	BD	PD
Sand	Silt	Clay		33.42	1519.5			(kg dm^{-3})	
				dag kg^{-1}					
732.9	142.1	125.0	SL	11.98	4.32	7.36	47.74	1.39	2.66

Note: pH-pH in 1:2.5 soil: Water suspension; OM—Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 M KCl at pH 7.0; H^+ and Al^{3+} extracted with 0.5 M CaOAc at pH 7; Na^+ and K^+ extracted with 1 M NH_4OAc at pH 7.0; ESP—Exchangeable sodium percentage; ECse—Electrical conductivity of the saturation extract of soil; SL—Sandy loam; AW—Available water; BD—Bulk density; PD—Particle density; *33.42 kPa–Field capacity, 1519.5 kPa–Permanent wilting point.

Each lysimeter was perforated at the bottom to allow drainage and attached to a 4-mm-diameter transparent tube. The tip of the tube inside the lysimeter was envolved with a nonwoven geotextile (Bidim OP 30) to avoid clogging by soil material. A plastic bottle was placed below each drain to collect the drained water, in order to estimate water consumption by of plants.

A spacing of 1.50 m between rows and 2.20 m between plants was established in the cultivation, using a trellis system with non-barbed wire n º14, installed inside the greenhouse, at 2.40 m from the floor and 1.60 m above the lysimeter. This trellis system supported passion fruit plants, which were conducted to the trellis using a string. When plant stem grew 10 cm above the trellis, the apical bud was removed to stimulate the production of two secondary branches, which were trained one to each side up to 1.10 m length.

After the secondary branches reached such length, the apical bud was removed again aiming at the production of tertiary branches, which were trained up to 30 cm from the soil, forming a curtain and producing inflorescences, which originated the fruits. Along the experiment, tendrils and unproductive branches were eliminated in order to favor crop development. Since plants were grown in a protected environment (greenhouse), pollination was carried out artificially (at 12:00).

Prior to transplanting, the water volume required to bring the soil to field capacity was determined, applying solutions according to the treatments. After transplanting, irrigation was carried out daily at 17:00, applying in each lysimeter solutions according to the treatment in order to maintain soil moisture at a level close to field capacity and avoid accumulation of salts in the soil. The amount applied was based on the requirement of the plants, estimated by water balance: volume applied minus volume drained in the previous irrigation, plus a leaching fraction of 0.15.

Fertilization was performed according to [22], applying 250 g of single superphosphate and 100 g of potassium chloride; at early flowering, 150 g of single superphosphate were applied in each plant. Fertilization with nitrogen and potassium was applied monthly, according to [23], using ammonium sulfate as source of nitrogen and potassium chloride as source of potassium. In the vegetative stage, a N:K ratio of 1:1 was used, taking as reference 10 g of nitrogen; from early flowering, nitrogen dose was increased to 20 g and K dose to 30 g, increasing the N:K ratio by 1:1.5.

Fruits were harvested as they became ripe and, at the end of the cycle (205 DAT), the following production variables were evaluated: total number of fruits per plant (TNF), determined by counting fruits per plant; mean fruit weight (MFW), obtained by the ratio between fruit weight and number of fruits per plant; total fruit weight (TFW), obtained by summing the weights of all fruits harvested per plant.

Physical quality of fruit was evaluated based on the following variables: fruit polar diameter (FPD), fruit equatorial diameter (FED), fruit rind thickness (FRT) and fruit pulp thickness (FPT). These parameters were measured immediately after harvest, using a digital caliper.

The quality of passion fruit quality was evaluated at the end of the cycle, through the following variables: hydrogen potential (pH), total titratable acidity (TTA) and vitamin C content (VIT C), according to the methodology described in [24]. To determine the chemical composition, ten passion fruits from each plot were used and all measurements were performed in triplicate.

The collected data were subjected to analysis of variance by F test at 0.05 probability level and, when significant, linear and quadratic polynomial regression analysis was carried out using the statistical program SISVAR ESAL [25]. When there was data heterogeneity, observed by the coefficient of variation, an exploratory analysis was carried out with data transformation to.

3. Results and discussions

According to Table 2, the levels of irrigation water salinity had significant effect on the variables NFP, TFW, FED, FRT and FPT, and there was no significant influence of H_2O_2 concentrations on the analysed variables. However, there was significant interaction between factors (SL × H_2O_2) for the variable FPD.

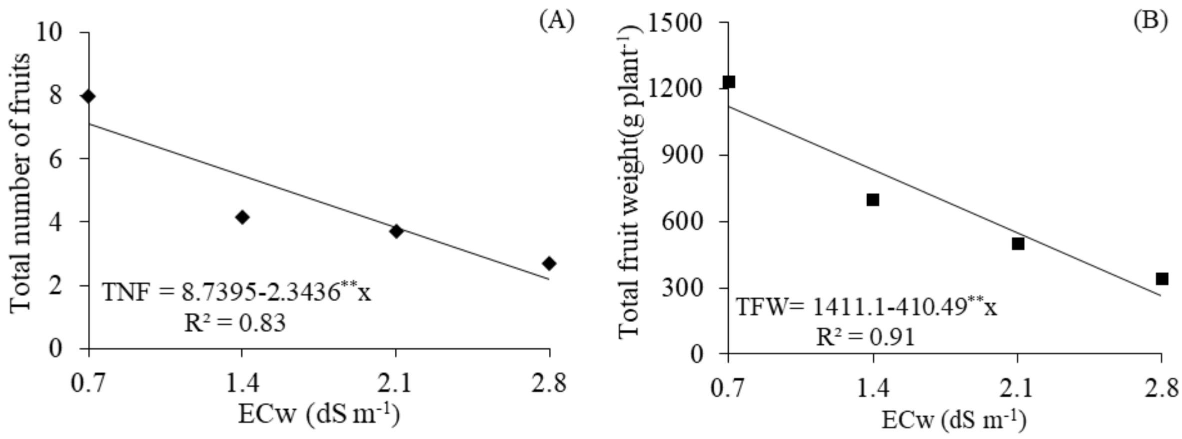
Table 2. Summary of F test for the variables total number of fruits per plant (TNF), mean fruit weight (MFW), total fruit weight per plant (TFW), fruit polar diameter (FPD), fruit equatorial diameter (FED), fruit rind thickness (FRT) and fruit pulp thickness (FPT) of yellow passion fruit under saline water irrigation and exogenous application of hydrogen peroxide, at 205 days after transplanting.

Source of variation	F Test TNF	MFW	TFW	FPD	FED	FRT	EPT[1]
Salinity levels (SL)	**	ns	**	ns	**	**	*
Linear regression	**	ns	**	ns	*	**	*
Quadratic regression	ns	ns	ns	ns	**	**	*
Hydrogen peroxide (H_2O_2)	ns	ns	ns	ns	ns	ns	ns
Interaction (SL $\times H_2O_2$)	ns	ns	ns	**	ns	ns	ns
Blocks	*	ns	**	ns	ns	ns	ns
CV (%)	23.41	27.00	16.53	6.40	10.31	8.96	12.71

*Note: [n.s.] **, * respectively, not significant, significant at P < 0.01 and P < 0.05. [1]data transformed to $\sqrt{x}$.

Irrigation using water of increasing salinity levels negatively affected NFP, TFW, FED, FRT and FPT. According to the regression equation (Figure 1A), NFP decreased linearly by 26.8% per unit increase in irrigation water electrical conductivity, i.e., when plants were irrigated using 2.8 dS m^{-1} water, NFP decreased by 69.4%, compared to those cultivated with 0.7 dS m^{-1} water. For TFW, the regression equation (Figure 1B) revealed a linear reduction of 29.09% per unit increase in irrigation water electrical conductivity, in other words, plants subjected to ECw of 2.8 dS m^{-1} showed reduction of 76.70% in TFW compared to those receiving 0.7 dS m^{-1} water. The reduction observed in passion fruit production variables, due to the increase in irrigation water salinity, may have resulted from the increase of salt concentration in the soil because salinity of both soil and water is considered one of the main causes of yield reduction, due to effects of osmotic, toxic and/or nutritional nature [26]. According to [27], salt stress increases the energy required to absorb water from the soil, weakening the plant, also due to the biochemical adjustment necessary for survival under stress. In addition, there is an increase in the energy expenditure for water absorption, due to the increment in the concentrations of salts applied via irrigation water [28].

In a situation of salt stress, plants tend to delay leaf production and reduce leaf area, in order to reduce water loss through transpiration, consequently affecting carbon assimilation and metabolic production [29]. Salt accumulation over time can compromise the number of flowers and even their fertility, not resulting in the formation of fruits, due to the effects caused by salt stress on biochemical and physiological processes of the plants [30]. In a study evaluating the physical quality and production of yellow passion fruit as affected by the use of biofertilizer and saline water irrigation (ECw varying from 0.5 to 4.5 dS m^{-1}), [30] found that increasing levels of irrigation water salinity caused reduction in the number of fruits per plant and, consequently, in fruit production.



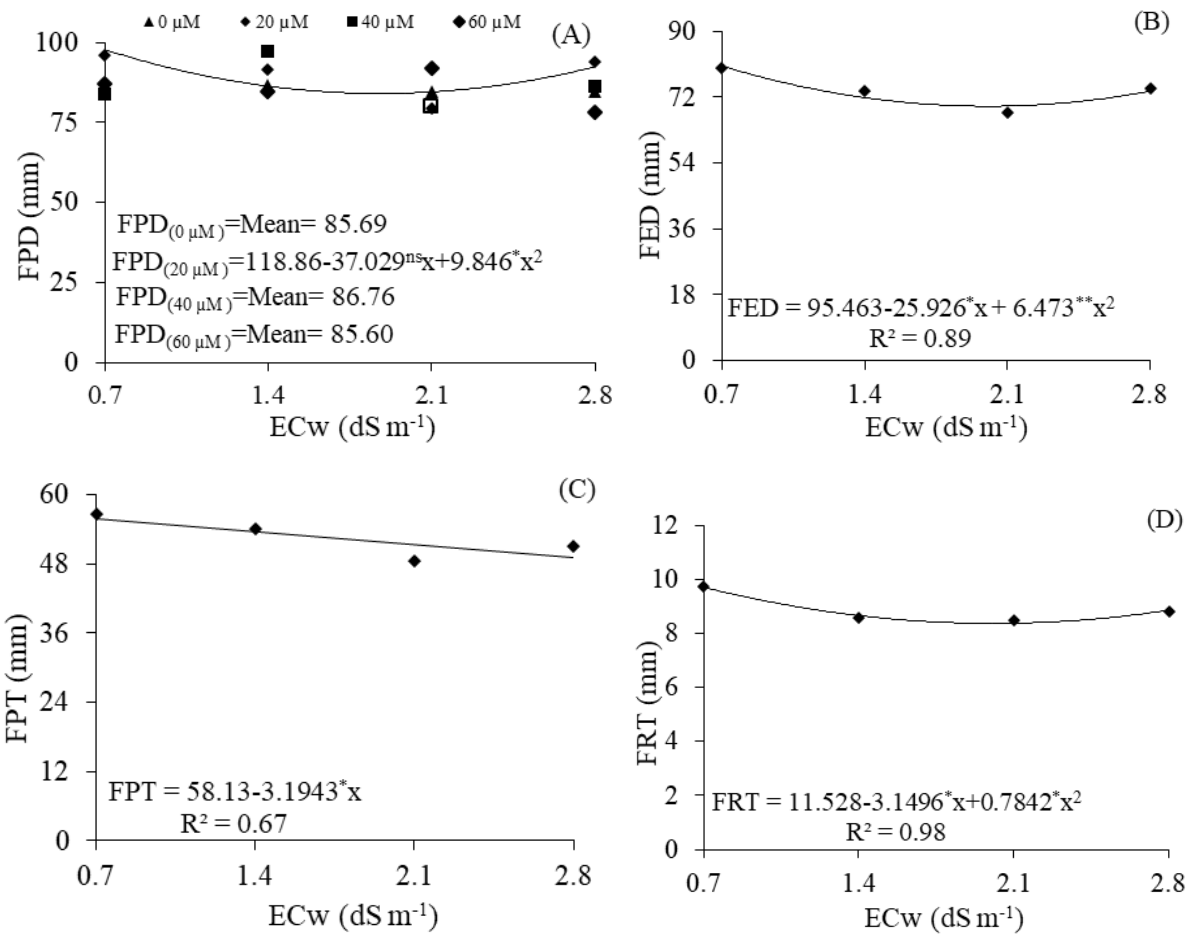
Note: **, significant at P < 0.01.

Figure 1. Total number of fruits per plant (A) and total fruit weight (B) of yellow passion fruit under saline water irrigation and exogenous application of hydrogen peroxide, at 205 days after transplanting.

Regarding the physical quality of yellow passion fruits, there was significant interaction between irrigation water salinity and H_2O_2 concentrations on FPD. For the concentration of 20 µM, the regression analysis (Figure 2A) showed that a quadratic model fitted best to the data, with highest FPD (97.76 mm) in plants irrigated using 0.7 dS m^{-1} water and lowest FPD (92.37 mm) in plants irrigated with 1.8 dS m^{-1} water, a reduction of 5.51% (5.63 mm). No regression model fitted to the other H_2O_2 concentrations, but mean values of 85.69, 86.76 and 85.60 mm were obtained in plants receiving exogenous application of H_2O_2 at concentrations of 0, 40 and 60 µM, respectively.

Despite the reduction in FPD, observed with increase in irrigation water salinity for the H_2O_2 concentration of 20 µM, it should be pointed out that this concentration led to the highest mean value for this variable (90.24 mm). This shows its higher efficiency in reducing salt stress because, according to [31], when applied at low concentrations in plants, H_2O_2 induces the defense system of antioxidant enzymes, minimizing the deleterious effects of salinity.

Fruit equatorial diameter was affected by irrigation with increasing levels of water salinity and, according to the regression analysis (Figure 2B), a quadratic model fitted best to the data, with highest estimated value in plants receiving 0.7 dS m^{-1} water (80.49 mm), compared to those irrigated with 2.8 dS m^{-1} water (73.60 mm), a reduction of 8.56% (6.89 mm). Similar results were found by [30], in a study evaluating the physical quality and production of yellow passion fruit cultivated with biofertilizer and saline water (ECw: 0.5 to 4.5 dS m^{-1}). These authors observed reductions of 41.3 and 49.2%, respectively, in equatorial and polar diameters in plants receiving water of 4.5 dS m^{-1} electrical conductivity in comparison to those irrigated with 0.5 dS m^{-1}. On the other hand, [32], studying the effect of irrigation water salinity (0.5, 2.5, 5.0 and 7.5 dS m^{-1}) on yellow passion fruit production, found no significant effect of irrigation water salinity on fruit length and diameter, but highlighted a trend of reduction in the variables as the levels of irrigation water salinity increased, obtaining mean values of 81.61 and 71.21 mm for fruit length and diameter, respectively.



*Note: ns, **, * respectively, not significant, significant at $P < 0.01$ and $P < 0.05$.

Figure 2. Fruit polar diameter (FPD) (A) and fruit equatorial diameter (FED) (B), fruit pulp thickness (FPT) (C) and fruit rind thickness (FRT) (D) of yellow passion fruit under saline water irrigation and exogenous application of hydrogen peroxide, at 205 days after transplanting.

Increasing levels of irrigation water salinity negatively affected the pulp thickness of yellow passion fruit. According to the regression equation (Figure 2C), FPT showed a decreasing linear response, reducing by 5.49% per unit increase in irrigation water electrical conductivity, i.e., passion fruit plants irrigated with 2.8 dS m^{-1} water showed reduction of 12.0% in FPT compared to those receiving 0.7 dS m^{-1} water. The rind thickness of yellow passion fruit was also negatively affected by saline water irrigation and, based on the regression analysis (Figure 2D), a quadratic model fitted best to the data, with highest estimated value of FRT in plants irrigated with 0.7 dS m^{-1} water (9.71 mm), compared to those receiving 2.8 dS m^{-1} water (8.86 mm). Reduction in passion fruit rind thickness as irrigation water salinity increased, was also observed by [30], obtaining values of 11.8 mm for the treatment of 0.5 dS m^{-1} and 8.7 mm for the treatment of 4.5 dS m^{-1} water salinity.

Different results were found by [12], in a study on the qualitative attributes of yellow passion fruit produced using saline water, biofertilizer and mulch on soil. These authors found no influence of irrigation water salinity levels on rind thickness and its mean values ranged from 7.11 to 8.15 mm for water salinity levels of 4.5 and 0.5 dS m^{-1}, respectively. According to these authors, the fruits are firm enough to be transported over long distances, which can reduce postharvest losses due to mechanical injuries, and are adequate for fresh commercialization and industrial processing. Based on these data, it can be noted that the values of passion fruit rind thickness obtained in the present study are close to the ones cited, favoring its commercialization and industrial processing.

The effect of salts on plants, due to the increased salt concentration in soil, contributed to the reduction in soil osmotic potential, toxicity by specific ions and imbalance in nutrient absorption by roots, causing overall loss in fruit quality [30], contributing to reductions in yellow passion fruit polar and equatorial diameters and pulp and rind thicknesses, as irrigation water salinity increased.

As shown in Table 3, the levels of irrigation water salinity and H_2O_2 concentrations had significant effect on passion fruit postharvest variables: hydrogen potential (pH), total titratable acidity (TTA) and vitamin C (VIT C). There was no significant interaction between factors (SL $\times H_2O_2$) for the evaluated variables.

The increase in irrigation water salinity levels negatively affected hydrogen potential (pH), total titratable acidity (TTA) and vitamin C contents (VIT C). Based on the regression analysis (Figure 3A), a quadratic model adjusted best to the data and pH increased up to the level of 2.3 dS m^{-1}, reaching maximum value of 3.03, decreasing from this level on and reaching a mean value of 3.01 in plants irrigated with 2.8 dS m^{-1} water. In a study on the quality attributes of passion fruit produced with saline water, biofertilizer and mulch on soil, [12] found that irrigation with saline water (4.5 dS m^{-1}) in soil under mulch reduced passion fruit juice pH, compared to plants receiving non-saline water (0.5 dS m^{-1}), from 3.49 to 3.33. The authors attributed such reduction to the presence of mulch on the soil, leading to higher conservation of moisture and production of organic acids absorbed by plants, resulting in higher acidity in fruit pulp.

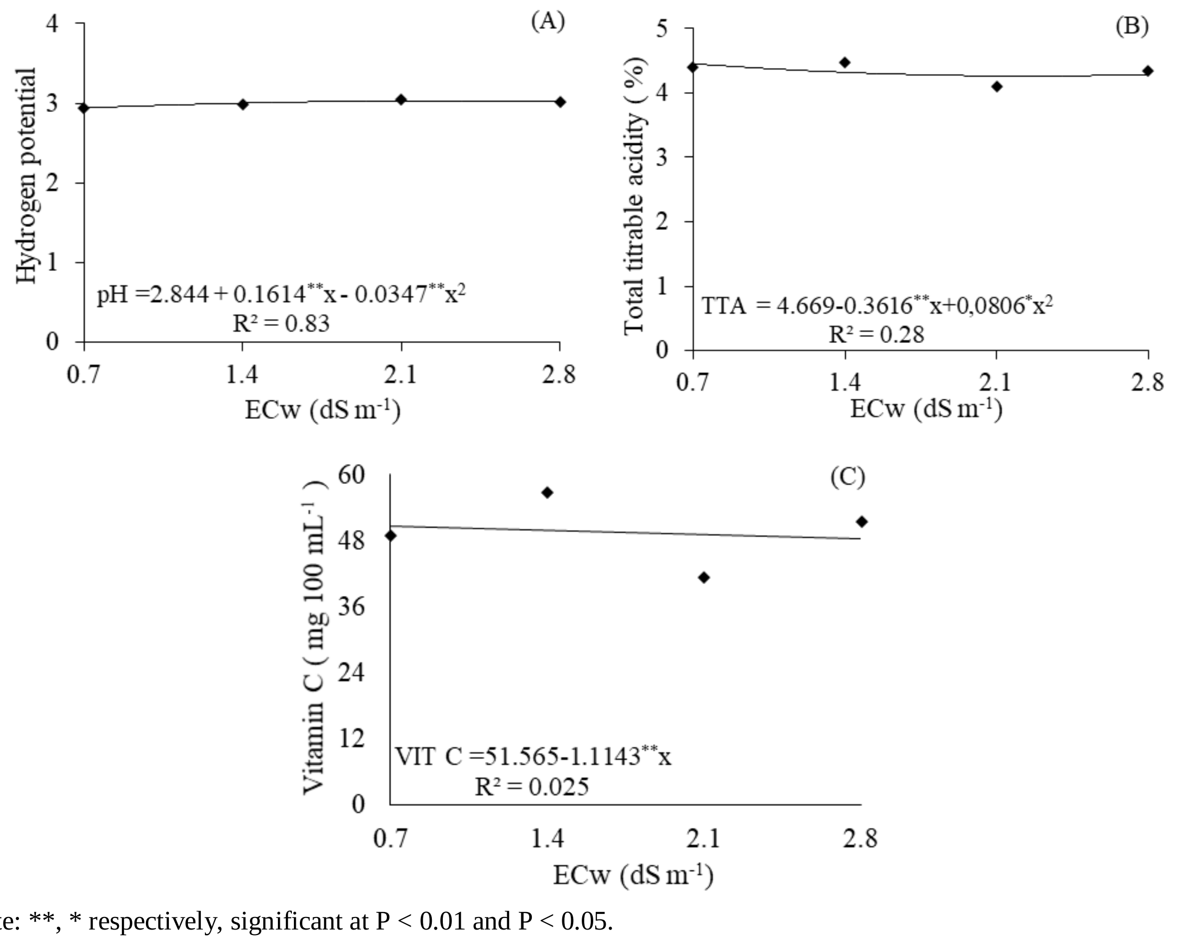
Similar results were also observed by [33], who found reduction in passion fruit juice pH when plants were irrigated with saline water (4.5 dS m^{-1}) compared to those which received non-saline water (0.5 dS m^{-1}), with values of 3.5 and 3.7, respectively. In this above-mentioned study, pH values were above 3.3, a value considered as ideal to maintain juice quality during storage, according to [34]. In the present study, the mean value obtained for pH was 3.0, considered as acid, but [35] emphasize that acid juice is desirable for industrial processing, since it reduces the need for adding acidifiers, lowers costs in the processing and increases juice shelf life.

For total titratable acidity, the regression analysis (Figure 3B) showed that a quadratic model fitted to the data, with highest value (4.45%) obtained in plants receiving 0.7 dS m^{-1} and lowest value (4.28%) in those cultivated with highest ECw level (2.8 dS m^{-1}), i.e., there was a 3.82% reduction between plants subjected to 2.8 dS m^{-1} and 0.7 dS m^{-1}. Different results were found by [21], who irrigated passion fruit plants using water with EC > 3.0 dS m^{-1} and noted that TTA values (3.33 and 3.87%) remained within the standards found in orchards irrigated with good-quality water. It should be mentioned here that the value of R^2 in this case is too low and hence cannot be used for predictive purposes. Despite the reduction in TTA observed as irrigation water salinity increased, its mean value was 4.33 for the applied treatments. As reported by [34], yellow passion fruit juice acidity should be between 3.2% and 4.5% for use in the processing industry, showing that the increment in the levels of irrigation water salinity up to 2.8 dS m^{-1} did not lead to TTA values outside the standards which are adequate for the industry.

Table 3. Summary of F test for the variables hydrogen potential (pH), total titratable acidity (TTA) and vitamin C (VIT C) in the pulp of yellow passion fruit under saline water irrigation and exogenous application of hydrogen peroxide, at 205 days after transplanting.

Source of variation	F Test		
	pH	TTA	VIT C
Salinity levels (SL)	**	**	**
Linear regression	**	**	**
Quadratic regression	**	*	**
Hydrogen peroxide (H_2O_2)	*	**	**
Linear regression	ns	ns	**
Quadratic regression	**	**	**
Interaction (SL x H_2O_2)	ns	ns	ns
Blocks	ns	ns	ns
CV (%)	1.17	2.93	2.08

*Note: **, * respectively, not significant, significant at P < 0.01 and P < 0.05.



*Note: **, * respectively, significant at P < 0.01 and P < 0.05.

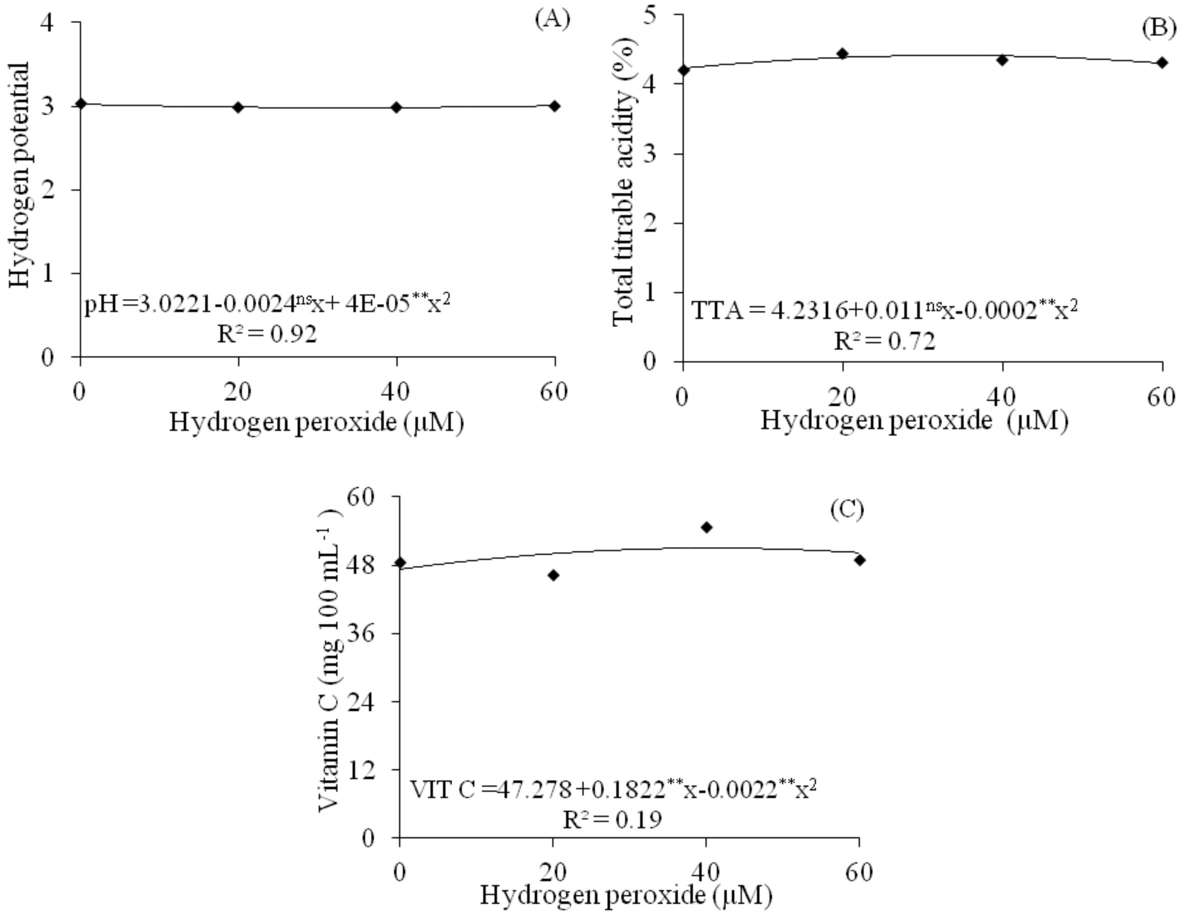
Figure 3. Hydrogen potential (pH) (A), total titratable acidity (TTA) (B) and vitamin C content (VIT C) (C) in the pulp of yellow passion fruit under saline water irrigation and exogenous application of hydrogen peroxide.

In relation to vitamin C contents, the regression analysis (Figure 3C) showed a decreasing linear response (though with value of R^2), with reduction of 2.16% per unit increase in irrigation water electrical conductivity, i.e., plants irrigated with 2.8 dS m^{-1} showed reduction of 4.60% in vitamin C contents, compared to plants grown with 2.8 dS m^{-1} water. Differently, in a study on the characterization of yellow passion fruits under saline water irrigation, [23] found that the use of saline water, with EC > 3.0 dS m^{-1}, did not interfere with the content of vitamin C in the fruits, whose mean value was 23.62 mg $100mL^{-1}$. For these authors, the maintenance of soil moisture, promoted by the mulch cover on the sides of the holes, resulted in lowering toxic and osmotic effects of salts on yellow passion fruit plants.

On the other hand, [12] observed that the highest vitamin C contents were obtained in fruits of passion fruit plants irrigated with non-saline water (0.5 dS m^{-1}) in soil with biofertilizer and irrigated with saline water (4.5 dS m^{-1}) in soil without the organic input and with mulch. In this situation, the mulch may have contributed to the conservation of soil moisture, favoring the dilution of the salts and alleviating the effects caused by them, allowing the occurrence of higher contents of vitamin C, even under irrigation with saline water (4.5 dS m^{-1}). In the present study, as already emphasized, the increase of salt concentration in soil due to the increment in irrigation water salinity possibly contributed to the reduction in VIT C contents, because of osmotic and toxic effects and nutritional imbalance, which may have compromised fruit quality.

Exogenous application of H_2O_2 concentrations significantly influenced pH, TTA and VIT C in yellow passion fruits and, according to the regression analysis (Figure 4A), a quadratic model fitted to the data, but there was no difference between pH values in plants receiving the maximum (60 µM) and minimum (0 µM) H_2O_2 concentrations, with mean value of 3.0. For TTA (Figure 4B), a quadratic model fitted to the data and TTA increased up to the concentration of 27.5 µM, with maximum of 4.38%, decreasing from this concentration and reaching a mean value of 4.17% in plants subjected to 60 µM. The increase in TTA caused by the concentration of 27.5 µM is possibly due to a higher efficiency of such concentration in the acclimation of yellow passion fruit plants. According to [36], exogenous application of H_2O_2 in leaf tissues or its endogenous induction acts as a signal of induction for the expression of genes related to catalase, ascorbate peroxidase, guaiacol peroxidase and glutathione reductase, and H_2O_2 accumulation in specific tissues and in appropriate amounts favors plants by mediating their acclimation and crossed tolerance to biotic and abiotic stresses.

For VIT C contents, the regression analysis (Figure 4C) showed that a quadratic model fitted best to the data, and VIT C increased up to the concentration of 41.5 µM, to a maximum value of 51.05, decreasing from this level on, and the concentration of 60 µM led to mean value of 50.29 mg $100mL^{-1}$. Possibly, higher H_2O_2 concentrations may have caused toxicity in yellow passion fruit plants, leading to reductions in VIT C contents. Since H_2O_2 is a reactive oxygen species (ROS), [37] states that plants are adapted to withstanding certain levels of ROS, but their accumulation in the tissues may cause toxicity and result in cell death. According to [38], such reduction may be due to the natural effect of H_2O_2 on plants because, at high concentrations, instead of promoting tolerance to stress, it favors toxicity and death of the plant due to the excess of H_2O_2 and other ROS.



Note: ns, **, * respectively, not significant, significant at $P < 0.01$ and $P < 0.05$.

Figure 4. Hydrogen potential (pH) (A), total titratable acidity (TTA) (B) and vitamin C contents (VIT C) (C) in the pulp of yellow passion fruit irrigated by different water salinity under exogenous application of hydrogen peroxide.

4. Conclusions

Irrigation water salinity negatively affected the production, physical and chemical quality of passion fruit, the number and total weight of fruits per plant being the most compromised variables at 205 days after transplanting. There was significant interaction between irrigation water salinity levels and hydrogen peroxide concentrations on fruit polar diameter. Foliar application of hydrogen peroxide at concentrations of 27.5 and 41.5 µM promoted higher values of total titratable acidity and vitamin C, respectively at 205 days after transplanting.

Conflict of interest

The authors declare no conflict of interest.

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