Article

Not peer-reviewed version

Production and Quality of West Indian Cherry under Salt Stress and NPK Fertilization Combinations

Antonio Manoel da Silva Filho * , Hans Raj Gheyi , Alberto Soares De Melo , André Alisson Rodrigues da Silva , Semako Ibrahim Bonou , Lumara Tatiely Santos Amadeu , Rener Luciano de Souza Ferraz , Patrícia da Silva Costa , Lucia Helena Garófalo Chaves , Rossana Maria Feitosa de Figueirêdo

Posted Date: 16 May 2023

doi: 10.20944/preprints202305.1079.v1

Keywords: Malpighia emarginata; water salinity; fertilization management

Article

Production and Quality of West Indian Cherry under Salt Stress and NPK Fertilization Combinations

Antonio Manoel da Silva Filho [1,*], Hans Raj Gheyi [1], Alberto Soares de Melo [2], André Alisson Rodrigues da Silva [1], Semako Ibrahim Bonou [1], Lumara Tatiely Santos Amadeu [1], Rener Luciano de Souza Ferraz [3], Patrícia Silva Costa [1], Lucia Helena Garofalo Chaves [1] and Rossana Maria Feitosa de Figueirêdo [1]

[1] Academic Unit of Agricultural Engineering – UAEA of the Federal University of Campina Grande – UFCG, Campina Grande, Paraiba, Brazil, manoel.silva@estudante.ufcg.edu.br; hans@pq.cnpq.br; andre.alisson@estudante.ufcg.edu.br; semako.ibrahim@estudante.ufcg.edu.br; lumaratatielyea@gmail.com; patriciagroambiental@gmail.com; lucia.garofalo@pesquisador.cnpq.br; rossana.maria@professor.ufcg.edu.br.

[2] Departament of Biology, State University of Paraiba, Campina Grande, Paraiba, Brazil; alberto.melo@servidor.uepb.edu.br

[3] Academic Unit of Development Technology – UATEC of the Federal University of Campina Grande – UFCG, in the municipality of Sumé, Paraiba, Brazil; rener.luciano@professor.ufcg.edu.br

* Correspondence: manoel.silva@estudante.ufcg.edu.br

Abstract: In the semi-arid region of Brazil, it is common to use saline or brackish water for crop production. However, this practice can negatively affect the soil, nutrient balance, and fruit quality and production. From this perspective, this study aimed to evaluate the effect of fertilization combinations with nitrogen (N), phosphorus (P), and potassium (K) on the production and quality of West Indian cherry grown under salt stress in the second year of production. The study was conducted in a protected environment following a randomized block design with treatments distributed in a 2 x 10 factorial arrangement referring to two levels of electrical conductivity of irrigation water (ECw) (0.6 and 4.0 dS m-1) and 10 NPK fertilization combinations (80-100-100; 100-100-100; 120-100-100; 140-100-100; 100-80-100; 100-120-100; 100-140-100; 100-100-80; 100-100-120 e 100-100-140% of the recommendation in the second year of production), with three replicates and one plant per lysimeter. The results indicate that irrigation of West Indian cherry crop irrigation at the water salinity of 4.0 dS m-1 negatively affected all fruit production variables. The interaction between the ECw of 0.6 dS m-1 and the 100-80-120 NPK fertilization combination increased the total number of fruits and the total fruit weight of West Indian cherry.

Keywords: *Malpighia emarginata;* water salinity; fertilization management

1. Introduction

West Indian cherry (*Malpighia emarginata* D. C.) is a tropical fruit species of the family Malpighiaceae, having originated in the Caribbean islands and Central and South Americas [1]. The fruits of this species show high contents of ascorbic acid (vitamin C), phenolic compounds (benzoic acid, flavonoids, and anthocyanins), and total carotenoids [2]. Furthermore, West Indian cherry also stands out due its high nutritional and economic potential as the fruits can be consumed fresh or processed into juices, ice creams, jellies, sweets, and other food products [3].

In northeastern Brazil, West Indian cherry cultivation has proven to be an economically important activity for the region, especially in its semi-arid portion, due to the species' adaptation to the local edaphoclimatic conditions [4,5]. However, it is known that the semi-arid region of Brazil is characterized, among other factors, by the frequent water restriction imposed by drought events, high evapotranspiration rates, and groundwater sources with high salt concentrations [6]. Therefore, the quantity and quality of available water in the semi-arid region of Brazil has limited the large-scale production of West Indian cherry and other fruit crops in that region [7].

In this scenario, the use of water with high-electrical conductivity (saline water) has become an increasingly common practice to irrigate crops such as West Indian cherry [7–9], passion fruit [10,11],

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2023 doi:10.20944/preprints202305.1079.v1

and sugar apple [12,13]. However, high salt concentrations in water can compromise the growth, physiology, production, and quality of fruits [13]. These disturbances occur mainly due to osmotic effects, which reduce water availability for plants [14], toxic effects caused by Cl^- and Na^+ ions [12], and the nutrient imbalance that imposes the deficiency of essential nutrients (Ca^{2+}, Mg^{2+}, K^+, and NO_3) due to the ion competition caused by the excess of chloride and sodium [15].

Given this limiting scenario, some alternatives have been studied aiming to mitigate the effects caused by salts on plants, including fertilization management, which seeks compensatory mechanisms for the nutrient deficiency caused by the interaction of toxic ions (Cl^- and Na^+) with essential nutrients and, consequently, their accumulation in plant tissues [11,12,16]. From this perspective, Sá et al. [4] obtained improvements in the growth, physiology, and production of the West Indian cherry cv. 'BRS Jaburu' during the first crop cycle when the recommended nitrogen and phosphorus levels were increased by 40% in plants irrigated with the electrical conductivity (ECw) of 3.0 dS m-1. Similarly, Lacerda et al. [9] observed that the combination of 70%-50% nitrogen and potassium of recommendation, respectively, reduced the effects of salt stress on the anthocyanin and ascorbic acid contents in West Indian cherry fruits.

From this perspective, this study aimed to evaluate the effect of combinations of nitrogen, phosphorus, and potassium on the production and quality of West Indian cherry grown under salt stress in the second year of production.

2. Materials and Methods

The experiment was conducted using drainage lysimeters under plant nursery conditions at the Agricultural Engineering Academic Unit of the Federal University of Campina Grande in Campina Grande, Paraíba, Brazil (coordinates: 7º 15′18″ S, 35º 52′28″ W, elevation of 550 m a.s.l.). Figure 1 shows the data referring to the maximum and minimum temperatures and relative air humidity obtained with a thermo-hygrometer, model Akso Simpla TH0, during the experimental period.

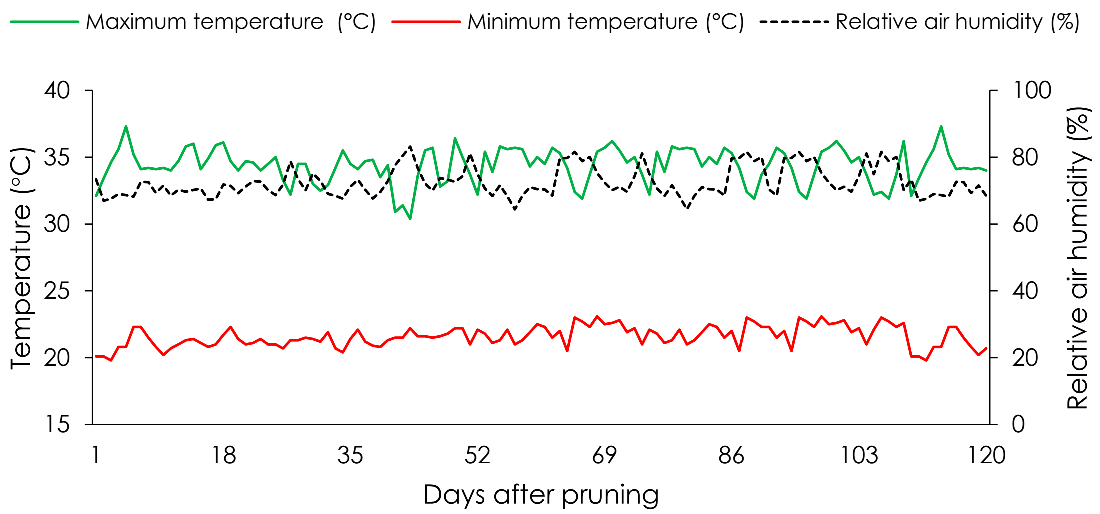


Figure 1. Daily maximum and minimum temperatures and relative air humidity inside the plant nursery during the experimental period.

The treatments were distributed in a 2 x 10 factorial arrangement following a randomized block design referring to two levels of electrical conductivity of irrigation water (ECw): 0.6 and 4.0 dS m^{-1}, and 10 combinations of fertilization (C) with nitrogen, phosphorus, and potassium (NPK): C_1 = 80-100-100%; C_2 (control) = 100-100-100%; C_3 = 120-100-100%; C_4 = 140-100-100%; C_5 = 100-80-100%; C_6 = 100-120-100%; C_7 = 100-140-100%; C_8 = 100-100-80%; C_9 = 100-100-120%; and C_{10} = 100-100-140%. These combinations were based on the fertilization combination for recommendation of $N-P_2O_5-K_2O$ suggested by Cavalcante [17] for the second crop cycle, with three replications, totaling 60 experimental units.

The control fertilization combination (100-100-100%) corresponded to the annual application of 100, 60, and 60 g of N, P_2O_5, and K_2O per plant, using as a reference the first year of cultivation. On the other hand, the saline treatments used in the present assay were based on the study of Silva et al. [18]. In March 2020, grafted West Indian cherry seedlings (using as rootstocks and scions the cultivars Junco and Flor Branca, respectively) were acquired from a commercial plant nursery registered with the National Registry of Seeds and Seedlings, located in the São Gonçalo District, Sousa, Paraíba, Brazil. At the end of the first experimental year, the West Indian cherry plants were subjected to water stress for 15 days, after which the pruning of the first cycle was performed and the second production year began. The electrical conductivity levels of irrigation water and NPK fertilization combinations with used in the second production year were the same as in the first year.

The seedlings were transplanted to 200-L drainage lysimeters whose bottoms were covered with geotextile fabric and filled with a layer of 1.0 kg of gravel and 239 kg of Entisol collected from the 0-20 cm soil layer in the municipality of Riachão do Bacamarte – PB with 7° 15' 34'' S and 35° 40' 1'' W. The physicochemical characteristics of the soil were determined according to Teixeira et al. [19], and the results are shown in Table 1.

Table 1. Chemical and physical characteristics of the soil (0-20 cm) used in the experiment before the application of treatments.

Chemical characteristics							
pH H_2O	O.M.	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	$Al^{3+} + H^+$
1:2.5	g dm^{-3}	mg dm^{-3}	………………cmol$_c$ kg^{-1}…………………				
6.5	8.1	79	0.24	0.51	14.90	5.40	0.90

……Chemical characteristics ……						……Physical characteristics ……				
EC_{se}	CEC	SAR_{se}	ESP	SB	V	Particle fraction (g kg^{-1})			Moisture content (dag kg^{-1})	
dS m^{-1}	cmol$_c$ kg^{-1}	(mmol $L^{-1})^{0.5}$	%	cmol$_c$ kg^{-1}	%	Sand	Silt	Clay	33.42 kPa[1]	1519.5 kPa[2]
2.15	21.95	0.16	2.3	21.05	95.89	572.7	100.7	326.6	25.91	12.96

pH – potential of hydrogen; O.M. – 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 NH_4OAC 1 M at pH 7.0; Al^{3+} + H^+ - extracted with CaOAc 0.5 M at pH 7.0; EC_{se} – Electrical conductivity of the saturation extract; CEC – Cation exchange capacity; SAR_{se} – Sodium adsorption ratio of the saturation extract; ESP – Percentage of exchangeable sodium; SB – Sum of bases ($K^+ + Ca^{2+} + Mg^{2+} + Na^+$); V – Base saturation ([SB/CEC] × 100); [1–2] – Referring to field capacity and the permanent wilting point, respectively.

With regard to the saline treatments, the water with the electrical conductivity levels of 0.6 and 4.0 dS m^{-1} were prepared by adding the salts NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ in a respective proportion of 7:2:1 to water available for irrigation in the study region (ECw = 0.38 dS m^{-1}), considering the relationship between the ECw and the concentration of salts proposed by Richards [20], according to Equation 1. The water electrical conductivity was monitored and adjusted periodically before irrigation.

$$Q \approx 10 \times ECw \tag{1}$$

Where: Q = sum of cations (mmol$_c$ L^{-1}) and ECw = water electrical conductivity (dS m^{-1}).

The treatments with saline water began to be applied 30 days after the seedlings were transplanted to the lysimeters following a two-day irrigation schedule. Each lysimeter received water according to the respective treatment, aiming to maintain soil moisture close to field capacity in all experimental units, estimated according to the soil water balance determined by Equation 2.

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

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2023 doi:10.20944/preprints202305.1079.v1

Where: VI = water to be used in the irrigation event (mL), Va = water volume applied in the previous irrigation event (mL), Vd = volume drained after the previous irrigation event (mL), and LF = 0.10 leaching fraction, applied every 90 days to prevent excessive salt accumulation in the soil solution.

The treatments with the fertilization combinations containing N, P, and K were split into 24 applications, always applied via topdressing, with 15-day intervals. The NPK sources used were calcium nitrate, monoammonium phosphate, and potassium sulfate, respectively. The fertilization interventions with micronutrients were performed every 15 days via foliar application on the adaxial and abaxial leaf surfaces by applying a solution containing 1.0 g L^{-1} of Dripsol® (Mg = 1.1%; Zn = 4.2%; B = 0.85%; Fe = 3.4%; Mn = 3.2%; Cu = 0.5%; and Mo = 0.05%). With regard to the crop management practices, first-cycle pruning, manual hoeing, soil scarification, and phytosanitary control were performed whenever necessary during the experimental period. For the second year of West Indian cherry production, the NPK combinations were adapted following the recommendation of Cavalcante [17], consisting of 200, 30, and 80 g of N, P_2O_5, and K_2O per year, respectively, per experimental unit. Therefore, in the second year of production, the application of treatments began 15 days after the first-cycle pruning (DAP) by maintaining the fertilization, irrigation, and phytosanitary managements used in the first year.

Harvest occurred when the fruits showed a red color but were still firm to withstand handling, corresponding to the commercial maturity stage. The total fruit weight (TFW, g) was quantified as the mass of the fruits harvested daily in each experimental unit during the production period. The total number of fruits (TNF) was obtained by counting all fruits harvested per plant in each plot. The mean fruit weight (MFW, g) was obtained by dividing the mean fruit weight by the total number of fruits harvested per plant. Furthermore, the polar (PFD - mm) and equatorial diameter (EFD - mm) of the fruits from each plot were evaluated individually by randomly choosing 20 fruits per plant. This procedure was performed using a digital caliper and measuring the distance from the apex to the base of the fruit (PFD) and in the equatorial region (EFD).

After analyzing the production variables, the fruits were pre-cleaned to eliminate those with damage or impurities. Then, the fruits were immersed for 15 min in chlorinated water (50 ppm) and washed in running water. The pulps were obtained by grinding the fruits in an industrial blender (BecKer®, modelo RBT-6) and passing them through a sieve to remove the uncrushed fiber fractions and other residues. Then, the pulps were stored in polyethylene bags and stored in a freezer at a controlled temperature of -18 °C until the analyses.

Characterization of the West Indian Cherry Pulps

The physicochemical parameters of the West Indian Cherry pulps were analyzed in triplicate, according to the methodology of the Adolfo Lutz Institute [21], by determining the total soluble solids (TSS, °Brix) using a portable refractometer (Euro Analytical, RZT model), the potential of hydrogen (pH) through direct reading in the samples using a digital potentiometer previously calibrated with buffer solutions at pH 4.0 and 7.0, the titratable acidity (TA, % citric acid), obtained by titration with 0.1 mol L^{-1} NaOH until reaching pH 8.2-8.4. The maturity ratio (RAT= TSS/TA) was obtained by the quotient between the total soluble solids and the titratable acidity, whereas the vitamin C content (VTC, mg ascorbic acid $100g^{-1}$) was estimated according to Oliveira, et al. [22].

The reducing sugars (RSU, g $100g^{-1}$) were determined using dinitrosalicylic acid [23] (Miller, 1959). The total phenolic compounds (TPC, mg $100g^{-1}$) were quantified with the Folin-Ciocalteu reagent [24]. The total anthocyanins (ANT, mg $100g^{-1}$) and flavonoids (FLA, mg $100g^{-1}$) were analyzed according to the recommendations of Francis [25]. All readings were performed in a spectrophotometer (BEL Photonics, model SP1102), according to their respective wavelength.

The data obtained were tested for the normality of distribution (Shapiro-Wilk test). Then, the analysis of variance was performed using the F-test ($p \leq 0.05$) for the electrical conductivity levels of irrigation water. In turn, the fertilization combinations (NPK) were compared using the Scott-Knott clustering test. All statistical analyses were performed using the software Sisvar [26].

3. Results and Discussion

According to the summary of the analyses of variance (Table 2), there was a significant interaction ($p \leq 0.01$) between the electrical conductivity of irrigation water and the NPK fertilization combinations for the total number of fruits (TNF), total fruit weight (TFW), and the mean fruit weight

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2023 doi:10.20944/preprints202305.1079.v1

(MFW). On the other hand, the electrical conductivity of irrigation water had a significant isolated effect ($p \leq 0{,}01$) on the equatorial fruit diameter (EFD) 140 days after pruning at the end of first cycle, during the second year of production.

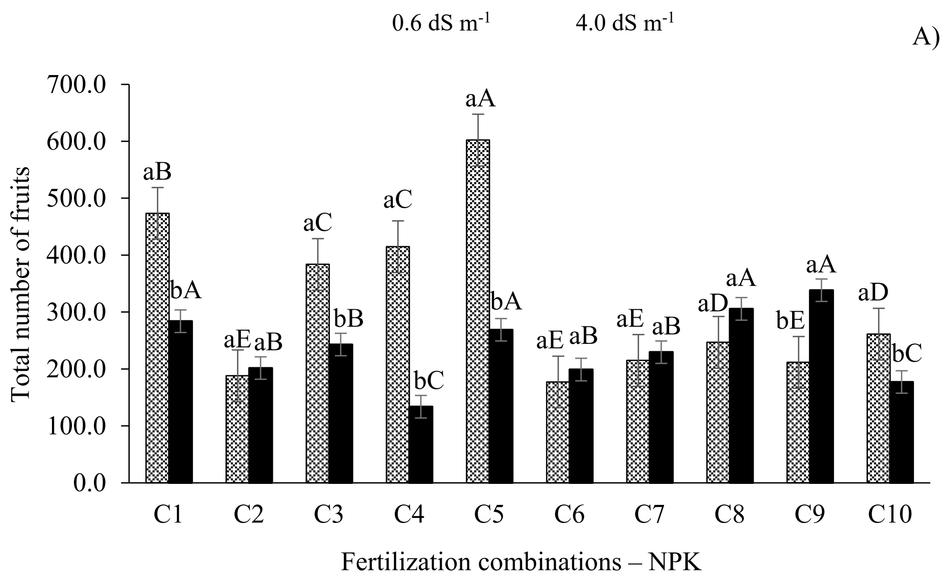
Table 2. Summary of the analysis of variance for the total number of fruits (TNF), total fruit weight (TFW), mean fruit weight (MFW), polar diameter (PFD), and equatorial diameter (EFD) of West Indian cherry irrigated with different electrical conductivity levels of irrigation water and combinations of nitrogen, phosphorus, and potassium (C) during the second year of production 140 days after pruning (DAP) during the second year of production.

Sources of variation	**GL**	**Mean Squares**				
		TNF	**TFW**	**MFW**	**PFD**	**EFD**
Water electrical conductivity - ECw	1	94318.627**	5667555.518**	15.347995**	1.532482^{ns}	18.734329**
Fertilization combinations - C	9	38502.571**	819854.9348**	1.283977**	2.652434^{ns}	4.346666^{ns}
Interaction (ECw × C)	9	35052.094**	1037320.541**	0.739933*	5.853079^{ns}	5.084948^{ns}
Block	2	2179.8871^{ns}	78568.0114^{ns}	0.110357^{ns}	10.996305^{ns}	6.016640^{ns}
Residual	38	1286.6893	73725.2114	0.329977	3.553961	2.675142
CV (%)		12.91	21.89	12.98	11.08	8.66

^{ns}, *, **, not significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

According to the unfolding of the data for the TNF of West Indian cherry (Figure 2), the electrical conductivity levels of irrigation water (0.6 and 4.0 dS m^{-1}) did not influence this variable significantly when the plants were subjected to fertilization combinations C_2 (100-100-100%), C_6 (100-120-100%), C_7 (100-140-100%), and C_8 (100-100-80%).

The highest values of fruit production were observed in plants irrigated with low-salinity water (0,6 dS m^{-1}) and under fertilization combinations C_5 (602.2), C_1 (473.5), C_4 (414.9), and C_3 (383.8), differing statistically from each other ($p \leq 0.01$) and from the plants irrigated with the ECw of 4.0 dS m^{-1} under combinations C_5 (269), C_1 (284.1) C_4 (133.9), and C_3 (243.1), respectively. On the other hand, the plants irrigated with the ECw of 4.0 dS m^{-1} showed the highest fruit production values under combinations C_9, C_8, C_5, and C_1, but only the C_9 combination differed ($p \leq 0.01$) from the plants irrigated with the ECw 0.6 dS m^{-1}.



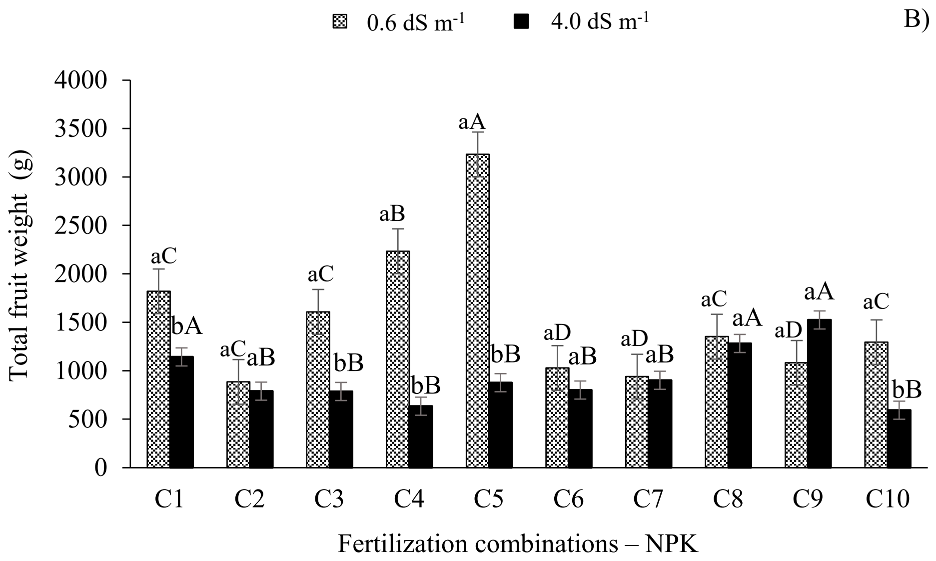


Figure 2. Unfolding of the interaction between the electrical conductivity levels of irrigation water and NPK fertilization combinations for the total number of fruits (A) and total fruit weight (B) of West Indian cherry 140 days after pruning during the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between the fertilization combinations by the Scott-Knott test at 0.05 of probability, whereas identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Means of three replicates ± standard error.

The plants irrigated with the ECw of 0.6 dS m^{-1} and associated with the fertilization combination containing 20% less phosphorus than the recommendation (C_5 = 100-80-100) showed a higher TNF compared to the other combinations, with mean increases of 68.75% and 70.55% in the TNF of West Indian cherry in relation to the plants fertilized with the recommended NPK levels (C_2 = 100-100-100%) and those that received 20% more of phosphorus (C_6 = 100-120-100%), which produced the lowest TNF values.

The plants irrigated with the ECw of 4.0 dS m^{-1} and associated with the fertilization combination with a 20% increase in potassium (C_9 = 100-100-120%) produced the highest TNF (338,5) but did not differ statistically from combinations C_1, C_5, and C_8. However, combination C_9 showed a higher TNF ($p \leq 0.01$) when compared with the lowest electrical conductivity. For combinations C_2, C_6, C_7, and C_8, despite the absence of a significant effect between each other, there were higher fruit production values in relation to the water with the lowest electrical conductivity studied. On the other hand, the lowest number of fruits (133.9) in this study was observed when the plants received water with the electrical conductivity level of 4.0 dS m^{-1} and fertilization combination C_4 (140-100-100%), although not differing from combination C_{10} (177.3) (Figure 2A).

Furthermore, the increase in the electrical conductivity of irrigation water to 4.0 dS m^{-1} reduced the mean TNF by 25%. However, in the plants under salt stress associated with combination C_9 (100-100-120%), there was an increase of 40.38% in the TNF in relation to the recommended fertilization levels (C_2) and of 60.45% compared to the combination with a 40% N increase (C_4 = 140-100-100), which showed the lowest TNF. The TNF reduction in plants under salt stress is possibly associated with salt accumulation in the soil solution, leading to a reduction in the osmotic potential and increasing the energy expenditure of the plant to absorb water and nutrients [27]. Therefore, these effects limit physiological and biochemical processes in the plant, restricting cell division and elongation and, consequently, reducing growth and fruit production [28], as observed in this study.

A similar behavior was observed for the total fruit weight (TFW), with the ECw levels studied not significantly affecting this variation under fertilization combinations C_2, C_6, C_7, C_8, and C_9 (Figure 2B). For the ECw of 0.6 dS m^{-1}, the highest TFW values were found when associated with

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2023 doi:10.20944/preprints202305.1079.v1

combinations C_5, C_4, C_1, C_3, and C_{10}, differing ($p \leq 0.01$) from the ECw level of 4.0 dS m^{-1}. Furthermore, the association between the ECw of 0.6 dS m^{-1} and the recommended N-P-K fertilization combination (C_2) generated the lowest TFW (885.16 g) value, on average 72.63% lower than the TFW observed in the treatment with combination C_5.

The highest electrical conductivity of irrigation water decreased the TFW by 39.71%. These results converge with those observed by Sá et al. [29], who observed a reduction of 217.48 g (20.3%) per plant in sugar apple (*Anonna squamosa* L.) plants subjected to the ECw of 3.0 dS m^{-1} in relation to those irrigated with 0.8 dS m^{-1}. For West Indian cherry, Silva et al. [28] observed that the increase in the ECw from 0.3 to 4.3 dS m^{-1} promoted a linear reduction of 3.95% in the mean fruit weight per unit increase in the ECw. On the other hand, the plants irrigated with the electrical conductivity of 4.0 dS m^{-1} under combination C_9 had TFW increases of 48.20% and 61.15% in relation to combinations C_2 and C_{10} (lowest TFW value), respectively (Figure 2B).

The electrical conductivity of 4.0 dS m^{-1}, when associated with combination C_9, resulted in the highest total fruit weight (1525.3 g), but did not differ from the value obtained with the lowest electrical conductivity in this fertilization combination. While, the lowest total fruit weight (592.57 g) was observed when the plants received the treatment with the highest electrical conductivity of irrigation water and fertilization combination C_{10}, not differing from the other treatments, except for C_1, C_8, and C_9 (Figure 3).

The results of this study indicate that, for the cultivation of West Indian cherry with the lowest electrical conductivity of irrigation water (0.6 dS m^{-1}), the combination containing 20% less the recommended phosphorus level provided greater nutritional balance, favoring physiological and biochemical processes in plants [27,30], which directly influenced the number and total weight of West Indian cherry fruits (Figure 2A,B). The importance of these results should be highlighted as they mean a reduction in the production cost of this crop in the semi-arid region.

At adequate levels, phosphorus favors root development, improves the water-use efficiency, nutrient uptake and utilization by plants, and acts in plant respiration, photosynthesis, and energy release for metabolic reactions [12,31]. Accordingly, Bezerra et al. [10] observed a reduction of 28.13% in the number of fruits in the second production cycle of guava due to the increase in the electrical conductivity of irrigation water from 0.3 to 3.5 dS m^{-1} and nitrogen fertilization. Ferreira et al. [12] also observed a 20.80% reduction in the number of sugar apple fruits with the increase in water salinity from 0.8 to 3.0 dS m^{-1} and fertilization with NPK.

On the other hand, the TNF increase under combinations C_6, C_7, C_8, and C_9 and the TFW increase under combination C_9 in plants subjected to salt stress, observed in the present study, are probably related to the increase in K availability (20%) since this nutrient acts in the osmotic regulation and in the activation of several enzymes that act in plant respiration and photosynthesis, directly affecting fruit production [29]. Furthermore, this effect could be related to the physiological role played by potassium in osmoregulation, intimately associated with the regulation of the cell osmotic potential and, consequently, contributing to homeostasis and fruit production [32]. From this perspective, Lima et al. [33] observed the mitigation of the negative effects of salinity on the total number of fruits and fresh fruit mass of West Indian cherry through potassium fertilization.

With regard to the mean fruit weight of West Indian cherry (Figure 3A), the plants irrigated with the electrical conductivity of 0.6 dS m^{-1} showed significant differences ($p \leq 0.01$) compared to the ECw of 4.0 dS m^{-1} under combinations C_3, C_5, C_6, and C_{10}. Furthermore, the plants irrigated with the ECw of 0.6 dS m^{-1} and associated with combinations C_4, C_5, C_6, C_7, C_8, C_9, and C_{10} obtained the highest MFW values without differing statistically, but differing ($p \leq 0.01$) from combinations C_1, C_2, and C_3.

 doi:10.20944/preprints202305.1079.v1

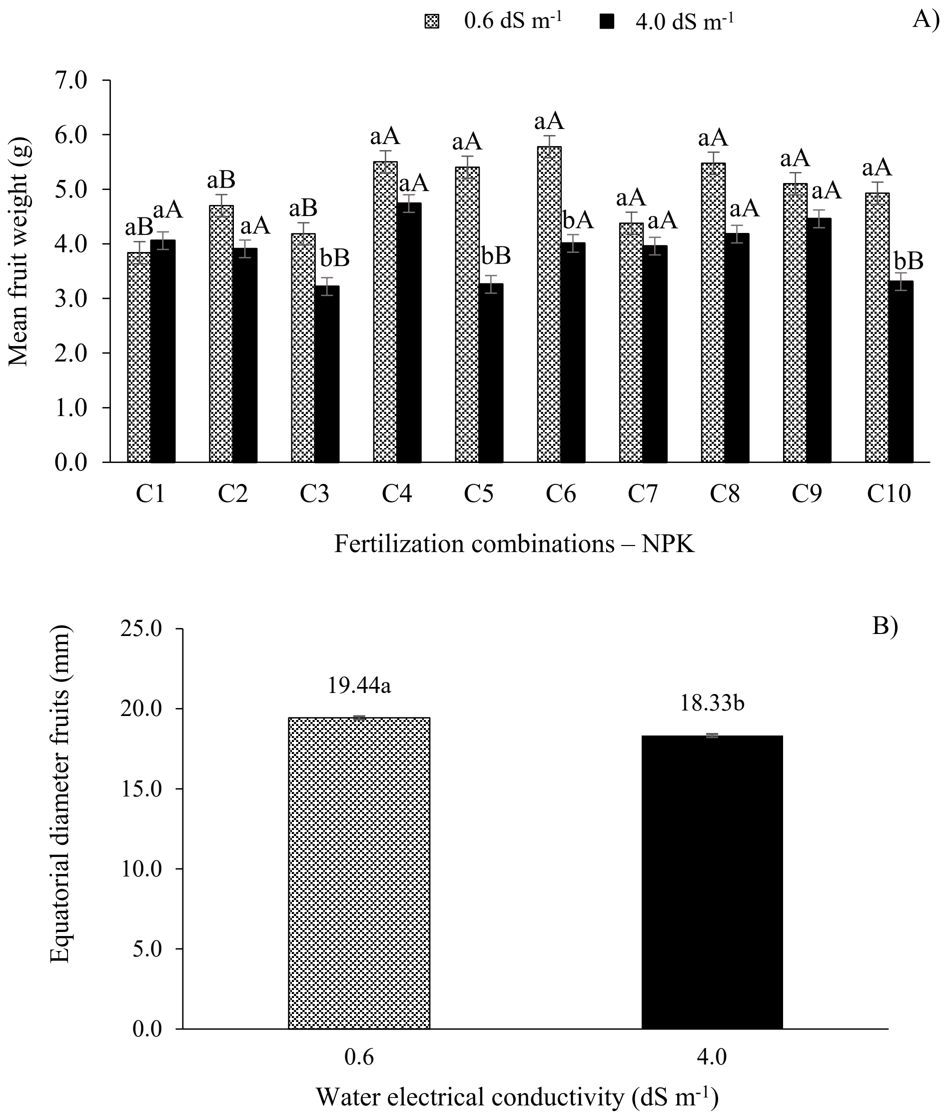


Figure 3. Mean fruit weight (A) and equatorial fruit diameter (B) of West Indian cherry as a function of the interaction between irrigation water salinity - ECw and NPK fertilization combinations 140 days after pruning during the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between fertilization combinations by the Scott-Knott test at 0.05 of probability. Identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Mean of three replicates ± standard error.

Similar to the behavior of TFW, the treatment with the salinity level of 0.6 dS m^{-1} and fertilization combination C_5 increased the MFW by 13.01% and 28.96% compared to the plants that received the recommended N-P-K combination (C_2 = 100-100-100%), and combination C_1 (80-100-100%) which showed the lowest MFW value (3.84 g). When applied at proper levels, phosphorus plays a key role in plant metabolism, especially due to its role in energy storage, which is vital for metabolic and structural functions such as photosynthesis [29]. Therefore, this result can be attributed to the reduction of 20% in the supplementation of P_2O_5 and the adequate N and K_2O levels present in combination C_6 (100-80-100%). Thus, even with West Indian cherry being a rustic plant, it easily adapts to various types of soil, highlighting the importance of properly managing fertilization and plant nutrition, especially with macronutrients such as P [33].

However, despite the MFW reductions in plants irrigated with the highest electrical conductivity (4.0 dS m^{-1}), the 40% increase in the recommended nitrogen level (C_4 = 140-100-100%) increased the MFW by 17.51% in relation to the recommended N-P-K levels (C_2), differing statistically ($p \leq 0.01$) from combinations C_3, C_5, and C_{10}.

Among the strategies used to mitigate the effects caused by salts, the management of fertilization has promoted positive effects on plant responses, especially when the fertilizer on focus is nitrogen-based. This effect can be justified by the role played by nitrogen in plants, composing several biomolecules, including amino acids, which act for osmotic adjustment and in the mitigation of the effects of reactive oxygen species [34].

Nitrogen is extremely important to plants as it acts in various structural functions and is part of vital organic compounds, e.g., the synthesis of amino acids, chlorophylls, proline, nucleic acids, proteins, etc. [13,27]. These functions are essential since they contribute to increasing the osmotic adjustment capacity of plants under water and salt stress [9,34]. From this perspective, Sá et al. [35] observed that 40% above the recommended N level for West Indian cherry was sufficient to mitigate the harmful effects caused by the ECw of 3.0 dS m^{-1}.

As observed in Figure 3B, the equatorial fruit diameter (EFD) of West Indian cherry decreased significantly ($p \leq 0.01$) as a function of the increase in the electrical conductivity of irrigation water regardless of the fertilization combination. Plants irrigated with the highest ECw (4.0 dS m^{-1}) showed EFD reductions of 5.71% (1.11 mm) compared to those subjected to the lowest ECw (0.6 dS m^{-1}).

Therefore, the EFD reduction observed in plants irrigated with the ECw of 4.0 dS m^{-1} could be related to the damage caused by the excess of salts in the cell membrane induced by reactive oxygen species [27]. Overall, salt stress causes different types of damage to plants due to the reduction in the osmotic potential of the soil solution, the nutrient imbalance caused by the excess of salts, and the disturbance in plant metabolism caused by the high concentration of toxic ions in the protoplasm, especially Cl^- and Na^+ ions [36].

Therefore, the set of these factors limits the uptake of essential nutrients, affecting plant growth, development, and production [9]. Therefore, it is essential to adopt tools with the potential to mitigate the effects of water salinity and use plant species with higher salt tolerance [12]. The excess of salts in the soil solution causes various types of damage to plants, including changes in stomatal conductance [27], changes in the quantum efficiency of photosystem II [8] and nutrient imbalance, which affects plant development [32], causes the de-structuration of membrane permeability [7], and restricts photosynthesis [16].

According to the summary of the analyses of variance shown in Table 3, there was a significant interaction ($p \leq 0.01$) between the electrical conductivity levels of irrigation water and the N-P-K fertilization combinations (ECw × C) on all post-harvest variables of West Indian cherry studied during the second production cycle.

Table 3. Summary of the F-test for total titratable acidity (TA, % citric acid), potential of hydrogen (pH), total soluble solids (TSS, ºBrix), TSS/TA ratio, vitamin C (VTC, mg $100g^{-1}$), reducing sugars (RSU, g $100g^{-1}$), total phenolic compounds (TPC, mg $100g^{-1}$), flavonoids (FLA, mg $100g^{-1}$), and anthocyanins (ANT, mg $100g^{-1}$) in West Indian cherry irrigated with saline water under different nitrogen, phosphorus, and potassium combinations (C) during the second year of production 140 days after the first-cycle pruning (DAP).

Sources of variation	F-test								
	TA	pH	TSS	RAT	VTC	RSU	TPC	FLA	ANT
Water electrical conductivity - ECw	**	**	**	**	**	**	ns	**	ns
Fertilization combinations - C	**	**	**	**	**	**	**	**	**
Interaction (ECw × C)	**	**	**	**	**	**	**	**	**
Block	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	0.71	0.22	1.32	1.49	2.46	3.70	3.01	3.63	3.56
General mean	1.78	3.36	9.63	5.39	3746	3030	2953	6.94	6.06

ns, *, **, indicate not significant and significant by the F-test at $p \leq 0.05$ and $p \leq 0.01$, respectively.

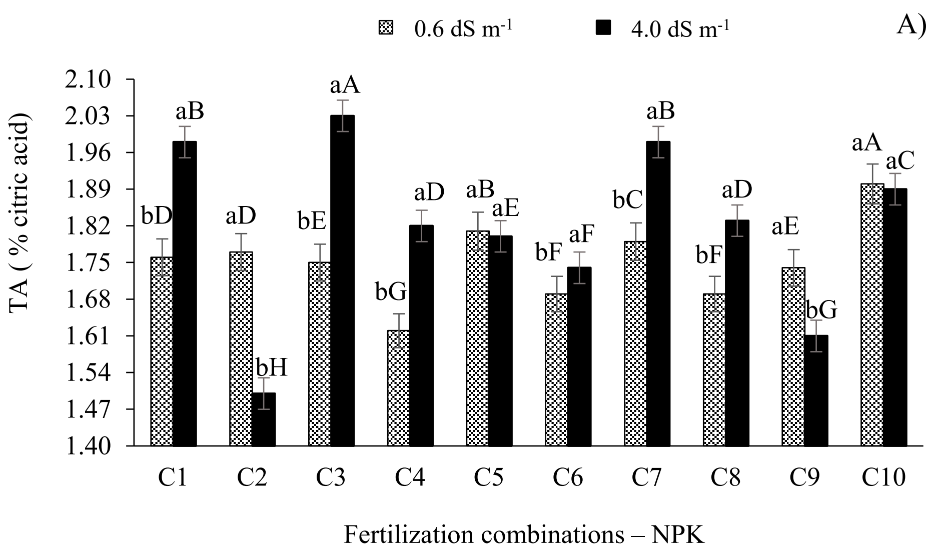
Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2023 doi:10.20944/preprints202305.1079.v1

The results shown in Figure 4A reveal that the titratable acidity (% citric acid) of West Indian cherry in plants irrigated with the electrical conductivity of 4.0 dS m^{-1} differed ($p \leq 0.01$) from those grown under the ECw of 0.6 dS m^{-1}, except in plants that received fertilization combinations C_{10} and C_5. Furthermore, the TA increased ($p \leq 0.01$) in plants irrigated with the highest salinity (4.0 dS m^{-1}) under fertilization combinations C_1, C_3, C_4, C_6, C_7, and C_8.

The saline treatment with the ECw of 4.0 dS m^{-1} associated with combination C_3 (120-100-100%) produced the highest titratable acidity in the fruit pulps, differing ($p \leq 0.01$) from other combinations. The TA increased by 12.81% and 26.11% in relation to the plants of the control treatment (C_2 - 100-100-100% of the recommended N-P-K level) when the plants were irrigated with the ECw levels of 0.6 and 4.0 dS m^{-1}, respectively.

The results of the titratable acidity of West Indian cherry pulp (Figure 4A) highlight its suitability for the processing of concentrated juice [16] and are important because the consumption of this fruit usually occurs through pulps, with the increase in the citric acid levels increasing the quality of the final product as this compound acts as an antioxidant and reduces the need for pulp acidifiers [10]. Adriano et al. [49] observed that, for ripe and semi-ripe West Indian cherry fruits, the TA was 3.15% and 3.26%, respectively.

In a study with the West Indian cherry cultivar 'BRS 366 Jaburu' irrigated with electrical conductivity levels ranging from 0.6 to 3.8 dS m^{-1} and phosphate fertilization, Lima et al. [7] obtained fruits with TA values ranging from 1.20% to 1.80%, i.e., values close to the mean values obtained in the present study, 1.75% and 1.82% of citric acid for the ECw of 0.6 and 4.0 dS m^{-1}, respectively. Furthermore, these TA values are significantly higher than the 0.94% obtained by Moura et al. [37] when studying the post-harvest of fruits of the West Indian cherry cv. Flor Branca, and the 0.80% recommended by Brazilian regulations [38].



Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 May 2023 doi:10.20944/preprints202305.1079.v1

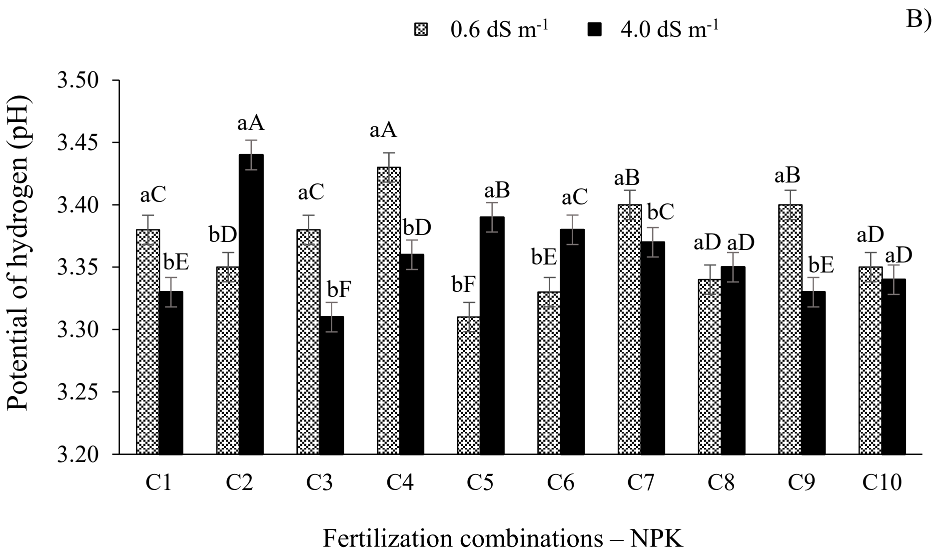


Figure 4. Titratable acidity (A) and potential of hydrogen (B) of West Indian cherry pulp as a function of the interaction between the electrical conductivity of irrigation water and combinations of NPK fertilization in the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between fertilization combinations by the Scott-Knott test at 0.05 of probability. Identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Mean of three replicates ± standard error.

For the pulp pH of West Indian cherry, the treatments with different electrical conductivity levels differed ($p \leq 0.01$) for all fertilization combinations, except C_8 and C_{10} (Figure 4B). There was a significant increase in the pulp pH of West Indian cherry in treatments irrigated with the ECw of 4.0 dS m^{-1} and associated with fertilization combinations C_2 (control), C_5, and C_6 in relation to the other combinations at the same salinity level (Figure 4B).

Given the results shown in Figure 4B, it is seen that the pulp pH of West Indian cherry decreased as a function of the increase in irrigation water salinity, increasing fruit acidity. The pulp pH value is extremely important as it represents the degree of pulp deterioration. According to Brazilian regulations [38], pulp pH values lower than 4.5 are ideal to prevent the proliferation of microorganisms and maintain pulp quality. Adriano et al. [49] analyzed the fruit quality of the West Indian cherry cv. Olivier and obtained pH values of 3.68 in ripe fruits and 3.56 in semi-ripe fruits, i.e., close to the values of the present study.

Lima et al. [7] studied the effects of ECw levels ranging from 0.6 to 3.8 dS m^{-1} and phosphate fertilization on the physicochemical quality of West Indian cherry and also observed a linear reduction in the pulp pH, with a reduction of 3.02% per unit increase in the electrical conductivity. On the other hand, Silva et al. [16] studied the fruit quality of the West Indian cherry cv. Flor Branca irrigated with saline water (ECw ranging from 0.30 to 4.30 dS m^{-1}) and combinations of nitrogen and potassium and did not observe significant effects on the pulp pH.

According to the results shown in Figure 5A, the plants irrigated with the electrical conductivity of 4.0 dS m^{-1} showed significant effects ($p \leq 0.01$) on the total soluble solids (ºBrix) of the pulp in relation to the plants grown under the ECw of 0.6 dS m^{-1}, except for combinations C_2 and C_3. The treatments with combinations C_1 and C_{10} under the ECw of 4.0 dS m^{-1} produced the highest TSS values, differing ($p \leq 0.01$) from the other fertilization combinations. The highest values of total soluble solids in West Indian cherry are related to the treatment with the ECw of 4.0 dS m^{-1} and combinations C_1 and C_{10}, which were, on average, 21.10% higher than the treatment with the recommended fertilization combination (C_2) under the same salinity treatment (Figure 5A).

Overall, the increase in the ECw levels increased the content of total soluble solids (ºBrix) of West Indian cherry pulp (Figure 5A). These results are important for this crop as the fruits are also marketed fresh, and high ºBrix concentrations correspond to high contents of sugars and organic acids [39]. Likewise, Lima et al. [7] observed that the increase in the ECw promoted linear increases in the soluble solids of West Indian cherry, whereas Silva et al. [16] observed no significant differences in the ºBrix of West Indian cherry in plants irrigated with different ECw levels. Adriano et al. [49] obtained the respective soluble solid values in ripe and semi-ripe fruits of 7.58 and 7.42 (ºBrix). Therefore, the TSS values found in this study are higher than the values of the authors mentioned before.

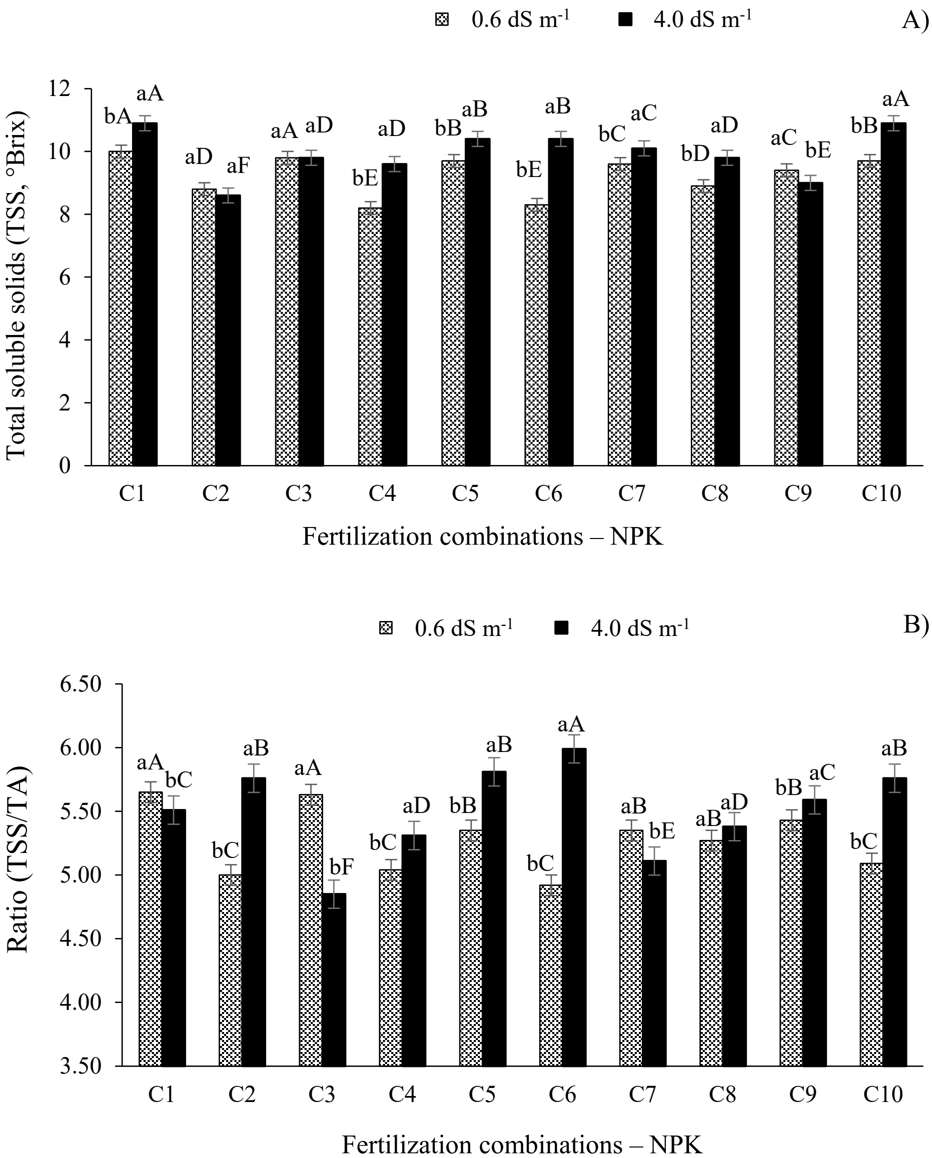


Figure 5. Total soluble solids (A) and maturity index ratio - TSS/TA (B) of West Indian cherry as a function of the interaction between the electrical conductivity of irrigation water and combinations of NPK fertilization evaluated in the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between fertilization combinations by the Scott-Knott test at 0.05 of probability. Identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Mean of three replicates ± standard error.

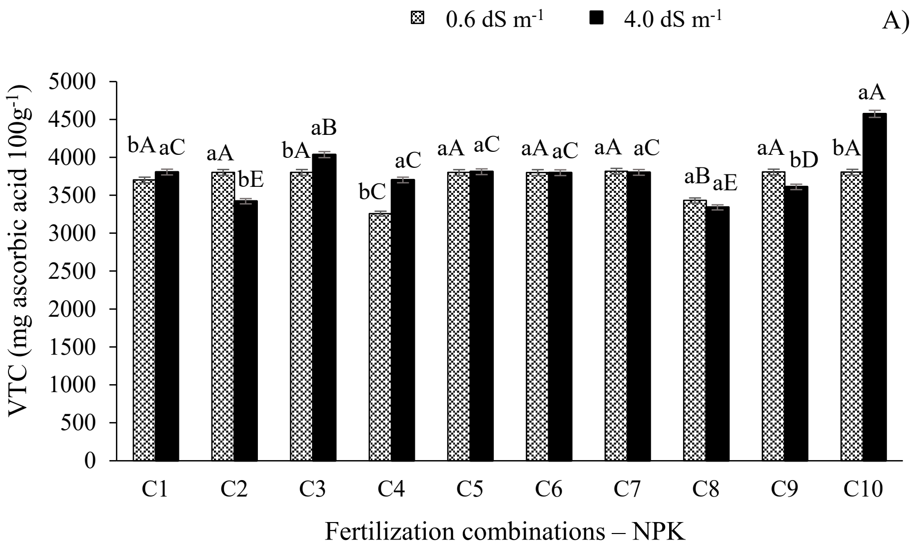
The significant effects ($p \leq 0.01$) of salt stress were also observed for the TSS/TA ratio (maturity index), except for combination C_8 (Figure 5B). Furthermore, the highest TSS/TA ratio value (5.99) was recorded in plants irrigated with the highest electrical conductivity and grown under combination

C_6 (100-120-100 % of the recommended N-P-K level), differing ($p \leq 0.01$) from the other fertilization combinations. For the plants irrigated with the ECw of 0.6 dS m^{-1}, the highest values of this index were observed when associated with combinations C_1 (5.65) and C_3 (5.63), differing ($p \leq 0.01$) from the other fertilization treatments.

The maturity index is represented by the relationship between total soluble solids and titratable acidity, corresponding to one of the main tools used to analyze fruit flavor since it represents the balance between these two variables [40]. Ferreira et al. [12] evaluated the production and post-harvest quality of sugar apple irrigated with saline water (ECw of 0.8 and 3.0 dS m^{-1}) and fertilized with different NPK combinations and observed that the highest values were obtained when using the NPK combination of 125-125-100% of recommendation. In another study, Silva et al. [16] observed no significant statistical differences in the maturity index of West Indian cherry in plants irrigated with different ECw levels and N-K combinations. Adriano et al. [49] obtained the TSS/TA ratio values of 2.41 and 2.27 for ripe and semi-ripe West Indian cherry fruits, respectively.

According to the unfolding of data for the contents of vitamin C of West Indian cherry (Figure 6A), there were statistical differences ($p \leq 0.01$) between the electrical conductivity levels studied. It is noted that the highest electrical conductivity of irrigation water (4.0 dS m^{-1}) and combination C_{10} caused the highest value of this variable, which was significantly higher ($p \leq 0.01$) than the other combinations. On the other hand, the plants irrigated with the ECw of 0.6 dS m^{-1} showed higher values of vitamin C when they plants received combinations C_2, C_6, C_7 C_8, and C_9, differing only from combinations C_4 and C_8.

Silva et al. [16] studied the production and quality of West Indian Cherry as a function of the increase in the ECw and NK combinations and observed a reduction of 2.16% in the vitamin C content of the fruits for every unit increase in the ECw of irrigation water. This reduction caused by the excess of salts in irrigation water is intimately related to the reduction in the contents of sugars with soluble hexoses, responsible for the synthesis of ascorbic acid by fruits [41].



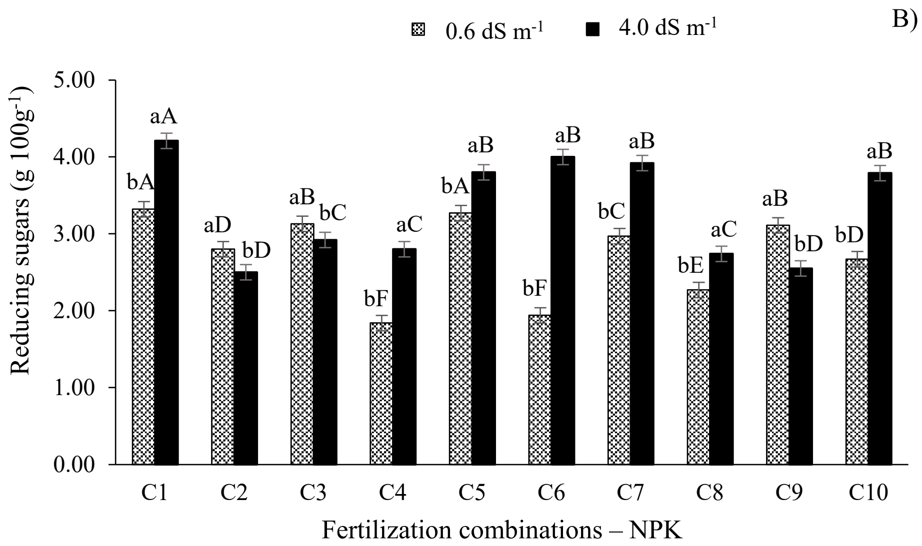


Figure 6. Vitamin C (A) and reducing sugars (B) of West Indian cherry pulp as a function of the interaction between the electrical conductivity of irrigation water and NPK fertilization combinations in the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between fertilization combinations by the Scott-Knott test at 0.05 of probability. Identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Mean of three replicates ± standard error.

The reducing sugars in the pulp of West India cherry fruits showed significant effects as a function of the electrical conductivity of irrigation water (Figure 6B). Despite the increase in the reducing sugars observed in plants irrigated with the ECw of 4.0 dS m^{-1}, only those plants grown under combination C_1 (80-100-100% of the recommended N-P-K level) differed ($p \leq 0.01$) from the other combinations, showing a 68.40% increase compared to the control plants (C_2) irrigated with the same salinity. For the treatments with the ECw of 0.6 dS m^{-1}, combination C_1 also produced the highest result for this variable, not differing only from combination C_5.

Given these results, it is seen that the supply of adequate N levels in plants under salt stress favors the biosynthetic pathways related to carbohydrates and maintains the balance in the assimilation of N and other essential nutrients, increasing the concentration of organic constituents such as sugars [42]. From this perspective, in both fresh fruit and those used for industrial processing, higher sugar contents are essential as they increase the sweetness and viscosity, in addition to improving the texture and decreasing the freezing point of the pulp [43]. Lacerda et al. [9] studied the quality of West Indian cherry fruits in plants irrigated with saline water and fertilized with nitrogen-potassium and observed linear reduction in the total sugar contents of the pulp, with reductions of up to 1.72% per unit increase in water salinity. In another study, Adriano et al. [49] obtained the respective values of 5.73 and 4.24 (g $100g^{-1}$) for ripe and semi-ripe West Indian cherry fruits.

For the phenolic compounds of West Indian cherry (Figure 7A), plants irrigated with the electrical conductivity of 4.0 dS m^{-1} showed the highest values for this parameter under fertilization combinations C_1, C_6, and C_{10}, which ($p \leq 0.01$) differed from the other combinations. On the other hand, in the treatment with the lowest electrical conductivity, combinations C_3, C_7, and C_{10} showed the highest values of phenolic compounds, differing from the other fertilization combinations.

As observed in Figure 7A, the highest values of phenolic compounds in West Indian cherry in plants under salt stress are associated with fertilization combinations C_1, C_4, C_5, C_6, C_8, and C_{10}, which differ from the plants irrigated with the ECw de 0.6 dS m^{-1} under combinations C_1, C_6, and C_8. Therefore, the availability of the optimum amount of N in plants under high salt concentrations in irrigation water can increase the CO_2 assimilation efficiency and other carbohydrate-related pathways, increasing the concentration of organic constituents in the fruit [44]. On the other hand, phosphorus acts in the energy metabolism, favoring the synthesis of nucleic acids, coenzymes, and sugars [12] and increasing the concentration of phenolic compounds in West Indian cherry under adverse conditions caused by salt stress, thus improving pulp quality [9].

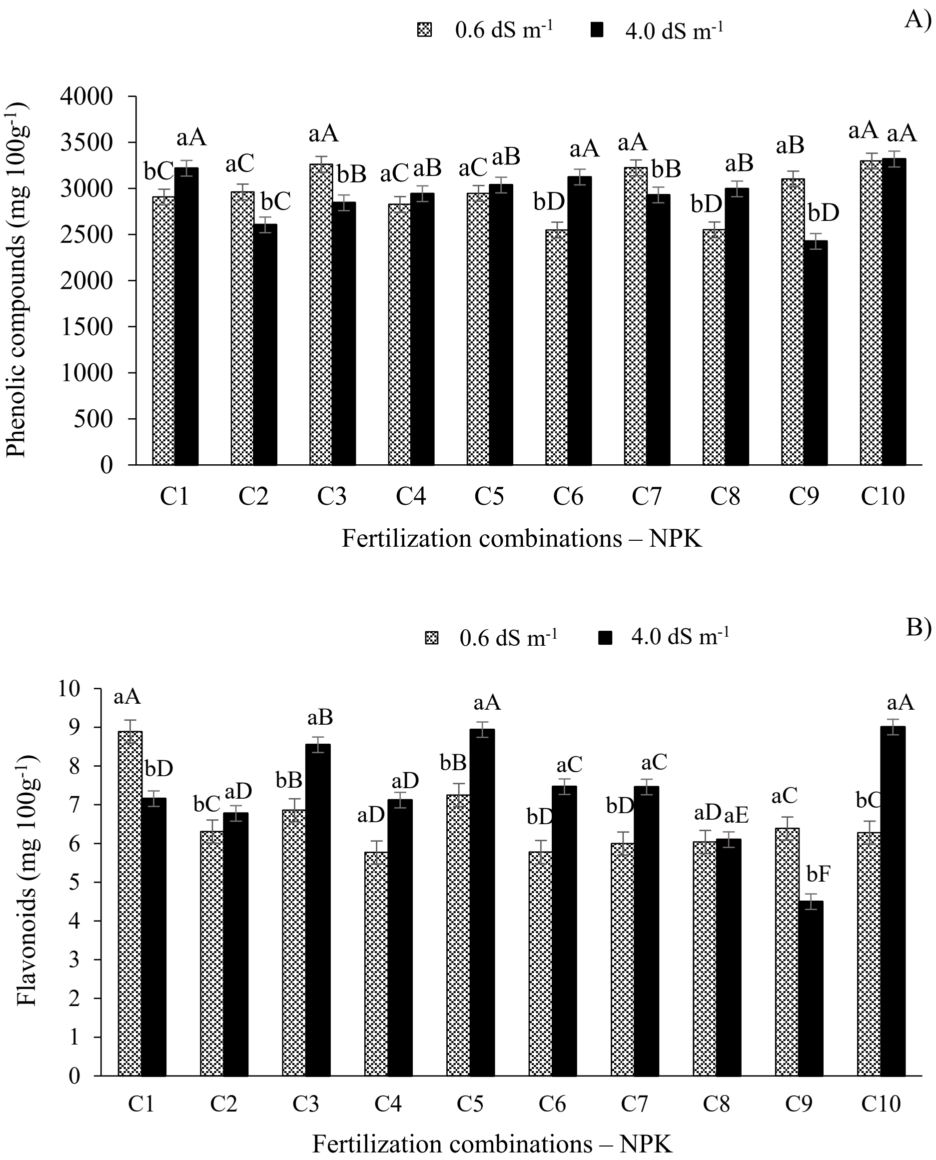


Figure 7. Phenolic compound (A) and flavonoids (B) in the pulp of West Indian cherry as a function of the interaction between the electrical conductivity of irrigation water and combinations of NPK fertilization in the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between fertilization combinations by the Scott-Knott test at 0.05 of probability. Identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Mean of three replicates ± standard error.

The flavonoid contents in the fruit pulp differ ($p \leq 0.01$) between the electrical conductivity levels (Figure 7B). Plants under the ECw of 4.0 dS m^{-1} and subjected to fertilization combinations C_5 and C_{10} performed better ($p \leq 0.01$) than the other combinations (Figure 7B). On the other hand, in plants irrigated with the lowest ECw (0.6 dS m^{-1}), the highest flavonoid content is associated with combination C_1, which differs from other fertilization combinations treatments (Figure 7B).

In the present study, the increase in the flavonoid content in West Indian cherry fruits under salt stress is mainly related to an adequate potassium supply since the fertilization combination that most favored their production was C_{10} (100-100-140% of the recommended N-P-K level). Potassium participates in some crucial functions in plants, e.g., the transport of amino acids and sugars to storage organs and enzyme activation [45]. Furthermore, the adequate supply of this macronutrient can increase its competition with other cations, especially Na^+ [46]. Therefore, these functions of potassium are essential in the cultivation of plants irrigated with high electrical conductivity levels.

According to the results shown in Figure 8, contents of anthocyanin in the pulp of West Indian cherry fruits were influenced ($p \leq 0.01$) by the electrical conductivity levels of irrigation water under all fertilization combinations except C_7. In plants irrigated with the ECw of 0.6 dS m^{-1}, the highest anthocyanin value was observed under combination C_1, differing from the other fertilization combinations. In plants irrigated with the ECw of 4.0 dS m^{-1}, the highest anthocyanin values were obtained under combinations C_5 and C_{10}, differing ($p \leq 0.01$) from the other combinations (Figure 8).

In the present study, the reduction in the anthocyanin contents of fruits observed in West Indian cherry plants irrigated with the highest ECw (4.0 dS m^{-1}) is possibly related to the reduction in the flavonoid contents [47]. High anthocyanin values are essential for West Indian cherry since this compound is responsible for the red color of the ripe fruit, constituting one of the essential aspects regarding the interest of consumers [48]. Lacerda et al. [9] observed a reduction in the anthocyanin contents when salinity increased up to 4.3 dS m^{-1} regardless of the fertilization combination with N-K.

From this perspective, it is necessary to adopt an increasingly effective management in crops subjected to salt stress, e.g., fertilization combinations with NPK.

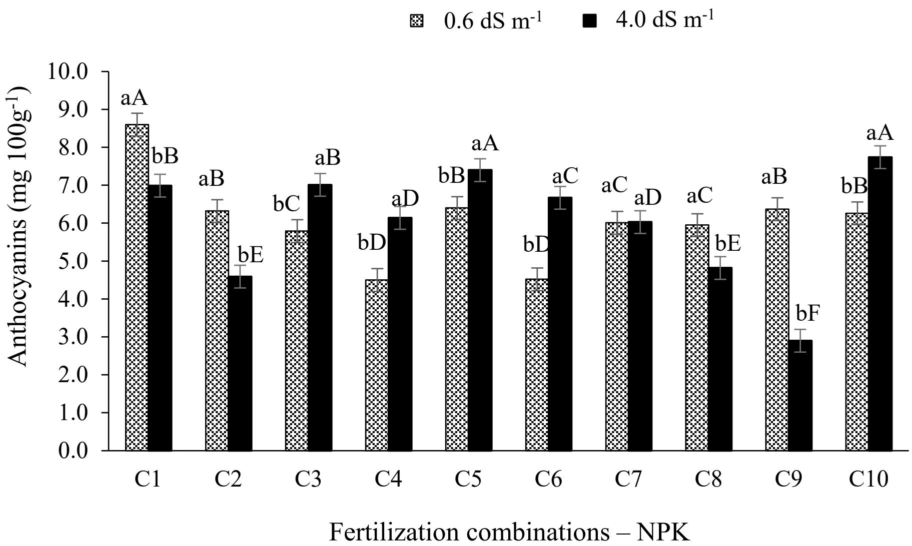


Figure 8. Anthocyanins (mg $100g^{-1}$) in the pulp of West Indian cherry fruits as a function of the interaction between the electrical conductivity of irrigation water and NPK fertilization combinations in the second year of production. C_1 = 80-100-100; C_2 = 100-100-100; C_3 = 120-100-100; C_4 = 140-100-100; C_5 = 100-80-100; C_6 = 100-120-100; C_7 = 100-140-100, C_8 = 100-100-80, C_9 = 100-100-120, and C_{10} = 100-100-140% of the recommended N-P_2O_5-K_2O level; Means followed by identical uppercase letters indicate that, for the same type of water, there are no significant differences between fertilization combinations by the Scott-Knott test at 0.05 of probability. Identical lowercase letters in the same fertilization combination indicate no significant difference between salinity levels (F-test, $p \leq 0.05$). Mean of three replicates ± standard error.

4. Conclusions

The irrigation of West Indian cherry with the water salinity of 4.0 dS m^{-1} negatively affected all production variables in the second year of production.

Plants irrigated with the water salinity of 4.0 dS m^{-1} and associated with the fertilization combination containing 100% N + 100% P_2O_5 + 120% K_2O favored the total number of fruits and the total fruit weight of West Indian cherry in the second year of production.

The interaction between the electrical conductivity irrigation water of 0.6 dS m^{-1} and the fertilization combination containing 100% N + 80% P_2O_5 + 120% K_2O increased the total number of fruits and the total fruit weight of West Indian cherry in the second year of production.

West Indian cherry plants irrigated with the irrigation water of electrical conductivity of 4.0 dS m^{-1} and associated with combinations C_1 (80-100-100%), C_3 (120-100-100%), C_6 (100-120-100%), and C_{10} (100-100-140%) of the recommended N-P-K level showed increases in the titratable acidity, total soluble solids, reducing sugars, TSS/TA ratio (maturity index), vitamin C, phenolic compounds, flavonoids, and anthocyanins compared to plants irrigated with the electrical conductivity level of 4.0 dS m^{-1}.

Author Contributions: Conceptualization, Hans Gheyi, Semako Bonou and Lumara Tatiely Santos Amadeu; Data curation, Hans Gheyi; Formal analysis, Antonio Manoel da Silva Filho, André Alisson Rodrigues da Silva, Semako Bonou, Lumara Tatiely Santos Amadeu and Patrícia da Silva Costa; Funding acquisition, Hans Gheyi; Investigation, Antonio Manoel da Silva Filho, Hans Gheyi and Alberto Melo; Methodology, Alberto Melo, André Alisson Rodrigues da Silva and Rener Luciano Ferraz; Project administration, Hans Gheyi; Resources, Antonio Manoel da Silva Filho, Hans Gheyi and Alberto Melo; Software, Antonio Manoel da Silva Filho and André Alisson Rodrigues da Silva; Supervision, Hans Gheyi and Alberto Melo; Validation, Antonio Manoel da Silva Filho, Hans Gheyi, Alberto Melo, Lucia Helena Garófalo Chaves and Rossana Figueirêdo; Visualization, André Alisson Rodrigues da Silva, Rener Luciano Ferraz, Lucia Helena Garófalo Chaves and Rossana Figueirêdo; Writing – original draft, Antonio Manoel da Silva Filho; Writing – review & editing, Antonio Manoel da Silva Filho, Hans Gheyi, Alberto Melo and Patrícia da Silva Costa. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Council of Scientific and Technological Development (CNPq), process of number CNPq. 151309/2019-1

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article. No supplemental data is provided.

Acknowledgments: The authors thank the Postgraduate Program in Agricultural Engineering of the Federal University of Campina Grande, the State University of Paraíba, the National Council of Scientific and Technological Development (CNPq), and the Coordination for the Improvement of Higher Education Personnel (CAPES) for their support for this research.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Ritzinger, R.; Ritzinger, C.H.S.P. Acerola. In: Cultivo tropical de fruteiras. Rodrigues, M.G.V.; Dias, M.S.C. (eds.). Belo Horizonte: EPAMIG, Informe Agropecuário, v.32, n.264, p.17-25, 2011.
2. Segtowick, E.C.S.; Brunelli, L.T.; Venturini Filho, W.G. Avaliação físico-química e sensorial de fermentado de acerola. *Brazilian J. Food Technol.* **2013**, 16, 147-154.
3. Calgaro, M.; Braga, M.B. A cultura da acerola. 3. ed. Brasília, DF: Embrapa, 2012. 144 p. (Coleção Plantar; 69).
4. Sá, F.V.S.; Gheyi, H.R.; Lima, G.S.; Paiva, E.P.; Silva, L.A.; Moreira, R.C.L.; Fernandes, P.D.; Dias, A.S. Ecophysiology of West Indian cherry irrigated with saline water under phosphorus and nitrogen doses. *Biosci J.* **2019**, 35, 211-221.
5. Silva, E.M.; Gheyi, H.R.; Nobre, R.G.; Lima, G.S.; Soares, L.A.A.; Bonifácio, B.F. Saline waters and nitrogen/potassium fertilization combinations on physiological aspects and production of West Indian cherry. *Rev. Ambient. Água* **2021**, 16, 1-14.
6. Medeiros, J.F.; Lisboa, R.A.; Oliveira, M.; Silva Júnior, M.J.; Alves, L.P. Caracterização das águas subterrâneas usadas para irrigação na área produtora de melão da Chapada do Apodi. *Rev. Bras. Eng. Agríc. Ambiental* **2003**, 7, 469-472.
7. Lima, G.S.; Silva, A.R.P.; Sá, F.V.S.; Gheyi, H.R.; Soares, L.A.A. Physicochemical quality of fruits of West Indian cherry under saline water irrigation and phosphate fertilization. *Rev. Caatinga* **2020**, 33, 217-225.

8. Dias, A.S.; Lima, G.S.; Sá, F.V.S.; Gheyi, H.R.; Soares, L.A.A.; Fernandes, P.D. Gas exchanges and photochemical efficiency of West Indian cherry cultivated with saline water and potassium fertilization. *Rev. Bras. Eng. Agríc. Ambiental* **2018**, 22, 628-633.
9. Lacerda, C.N.; Lima, G.S.; Silva, E.M.; Nobre, R.G.; Gheyi, H.R.; Soares, L.A.A. Fruit quality of West Indian cherry under saline water irrigation and nitrogen-potassium fertilization. *Rev. Bras. Eng. Agríc. Ambiental* **2021**, 25, 741-749.
10. Bezerra, M.A.F.; Cavalcante, L.F.; Bezerra, F.T.C.; Silva, A.R.; Oliveira, F.F.; Medeiros, S.A.S. Saline water, pit coating and calcium fertilization on chlorophyll, fluorescence, gas exchange and production in passion fruit. *J. Agric. Sci.* **2019**, 11, 319-329.
11. Lima, G.S.; Fernandes, C.G.J.; Soares, L.A.A.; Gheyi, H.R.; Fernandes, P.D. Gas exchange, chloroplast pigments and growth of passion fruit cultivated with saline water and potassium fertilization. *Rev. Caatinga*, **2020**, 33, 184-194.
12. Ferreira, F.N.; Lima, G.S.; Gheyi, H.R.; Sá, F.V.S.; Dias, A.S.; Soares, L.A.A. Production and post-harvest quality of custard apple irrigated with saline water and fertilized with N-P-K. *Comun. Sci.* **2022**, 13, 1-9.
13. Silva, A.A.R.; Veloso, L.L.S.A.; Lima, G.S.; Gheyi, H.R.; Sá, F.V.S.; Azevedo, C.A.V. Cultivation of custard-apple irrigated with saline water under combinations of nitrogen, phosphorus and potassium. *Rev. Caatinga* **2022**, 35, 181-190.
14. Moreira, R.C.L.; Brito, M.E.B.; Fernandes, P.D.; Sá, F.V.S.; Silva, L.A.; Oliveira, C.J.A.; Veloso, L.L.S.; Queiroga, T.B. Growth and physiology of *Annona squamosa* L. under different irrigation depths and phosphate fertilization. *Biosci J.* **2019**, 35, 389-397.
15. Pinheiro, F.W.A.; Lima, G.S.; Gheyi, H.R.; Soares, L.A.A.; Oliveira, S.G.; Silva, F.A. Gas exchange and yellow passion fruit production under irrigation strategies using brackish water and potassium. *Rev. Cienc. Agron*. **2022**, 53, 1-11.
16. Silva, E.M.; Gheyi, H.R.; Nobre, R.G.; Barbosa, J.L.; Santos, B.G.F.L.; Oliveira, S.G.; Silva, E.L.; Guedes, M.A. Fruit quality of West Indian cherry irrigated with saline waters under combinations of nitrogen/potassium fertilization. *Biosci J.* **2020**, 36, 1238-1250.
17. Cavalcante, F.J.A. Recomendação de adubação para o Estado de Pernambuco: 2. aproximação. 3.ed. Recife: Instituto Agronômico de Pernambuco, 2008. 212p.
18. Silva, E.M.; Gheyi, H.R.; Nobre, R.G.; Barbosa, J.L.; Oliveira, V.K.N.; Silva, L.A. Photosynthesis and production of West Indian cherry irrigated with saline waters under nitrogen/potassium fertilization. *Comun. Sci.* **2020**, 11, 1-11.
19. Teixeira, P.C.; Donagemma, G.K.; Fontana, A.; Teixeira, W.G. Manual de métodos de análise de solo. 3.ed. Brasília, DF: Embrapa Solos, 2017. 573 p.
20. Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington, DC: U.S, Department of Agriculture. 1954. 160 p. USDA Handbook 60.
21. IAL - Instituto Adolfo Lutz. Métodos físico-químicos para análise de alimentos. 4.ed., 1.ed. digital. São Paulo: IAL, 2008. 1020p.
22. Oliveira, R. Godoy, H.; Prado, M. Otimização de metodologia colorimétrica para determinação de ácido ascórbico em geleia de frutas. *Ciênc. Tecnol. Aliment*. **2010**, 30, 244-249.
23. Miller, G.L. Use of dinitrosalicylic acid reagent for determination of reducing sugar, *Analytical ChemistryWashington*, **1959**, 31, 426-428.
24. Pinelo, M.; Laurie, V.F.; Waterhouse, A.L. A Simple Method to Separate Red Wine Nonpolymeric and Polymeric Phenols by Solid-Phase Extraction. J. Agric. Food Chem. **2006**, 54, 2839–2844.
25. Francis, F.J. Analysis of anthocyanins. In: Markakis, P. (ed.). Anthocyanins as food colors. New York: Academic Press, 1982. p.181-207.
26. Ferreira, D.F. Sisvar: A computer analysis system to fixed effects split plot type designs. *Rev.Bras.Biom.* **2019**, 37, 529-535.
27. Taiz, L.; Zeiger, E.; Moller, I.; Murphy, A. Fisiologia e desenvolvimento vegetal. 6.ed. Porto Alegre: Artmed, 2017. 888 p.

28. Silva, E.M.; Gheyi, H.R.; Nobre, R.G.; Barbosa, J.L.; Souza, C.M.A. Morphology and production of West Indian cherry irrigated with saline waters under combinations of nitrogen-potassium fertilization. *Rev. Caatinga*, **2019**, 32, 1027-1037.
29. Sá, F.V.S.; Gheyi, H.R.; Lima, G.S.; Pinheiro, F.W.A.; Paiva, E.P.; Moreira, R.C.L.; Silva, L.A.; Fernandes, P.D. The right combination of N-P-K fertilization may mitigate salt stress in custard apple (*Annona squamosa* L.). *Acta Physiol. Plant.* **2021**, 43, 1-12.
30. Sá, F.V.S.; Gheyi, H.R.; Lima, G.S.; Paiva, E.P.; Lacerda, C.F.; Fernandes, P.D. Saline water, nitrogen and phosphorus on water relations and physiological aspects of West Indian cherry. *Comun. Sci.* **2018**, 9, 430-437.
31. Simão, E.P.; Resende, Á.V.; Gontijo Neto, M.M.; Borghi, E.; Vanin, À. Resposta do milho safrinha à adubação em duas épocas de semeadura. *Rev. Bras. Milh. Sorg*. **2018**, 17, 76-90.
32. Alvarenga, C.F.S.; Silva, E.M.; Nobre, R.G.; Gheyi, H.R.; Lima, G.S.; Silva, L.A. Morfofisiologia de aceroleira irrigada com águas salinas sob combinações de doses de nitrogênio e potássio. *Rev. Cienc. Agrar.* **2019**, 42, 194-205.
33. Lima, G.S.; Dias, A.S.; Souza, L.P.; Sá, F.V.S.; Gheyi, H.R.; Soares, L.A.A. Effects of saline water and potassium fertilization on photosynthetic pigments, growth and production of West Indian Cherry. *Rev. Ambient. Água*, **2018**, 13, 1-12.
34. Ashraf, M.; Shahzad, S.M.; Imtiaz, M.; Rizwan, M.S.; Arif, M.S.; Kausar, R. Nitrogen nutrition and adaptation of glycophytes to saline environment: a review. *Arch. Agron. Soil Sci.* **2018**, 64, 1181-1206.
35. Sá, F.V.S.; Gheyi, H.R.; Lima, G.S.; Paiva, E.P.; Fernandes, P.D.; Moreira, R.C.L.; Silva, L.A.; Ferreira Neto, M. Water relations and gas exchanges of West Indian cherry under salt stress and nitrogen and phosphorus doses. *J. Agric. Sci.* **2017**, 9, 168-177.
36. Ouhaddach, M.; Elyacoubi, H.; Douaik, A.; Rochdi, A. Morpho-physiological and biochemical responses to salt stress in wheat (*Triticum aestivum* L.) at the heading stage. *J. Mater. Environ. Sci.* **2018,** 9, 1899-1907.
37. Moura, C.F.H.; Alves, R.E.; Figueiredo, R.W.; Paiva, J.R. Avaliações físicas e físico-químicas de frutos de clones de aceroleira (*Malpighia emarginata* D.C.). *Rev. Cienc. Agron*. **2007,** 38, 52-57.
38. Brasil - Ministério da Agricultura do Abastecimento. Instrução normativa nº 1, de 07 de janeiro de 2000. Padrão de identidade e qualidade para polpas de frutas. 2000. 26p.
39. Nascimento Filho, E.; Silva, N.N.B.; Converti, A.; Grosso, C.R.F.; Santos, A.M.P.; Ribeiro, D.S.; Maciel, M.I.S. Microencapsulation of acerola (*Malpighia emarginata* DC) and ciriguela (*Spondias purpurea* L) mixed juice with different wall materials. *Food Chem. Adv.* **2022**, 1, 1-8.
40. Chitarra, M.I.F.; Chitarra, A.B. Pós colheita de frutas e hortaliças: fisiologia e manuseio. 2.ed. Lavras: UFLA, 2005.
41. Dias, T.J.; Cavalcante, L.F.; Nunes, L.C.; Freire, J.L.O.; Beckmann-Cavalcante, M.Z.; Santos, G.P. Qualidade física e produção do maracujá amarelo em solo com biofertilizante irrigado com águas salinas. *Rev. Bras. Eng. Agríc. Ambiental*, **2011**, 15, 229-236.
42. Marschner, H. Marschner's mineral nutrition of higher plants. 3.ed. Amsterdam: Academic Press, 2012, 649p.
43. Brasil - Ministério da Agricultura do Abastecimento. Instrução normativa nº 37, de 1º de outubro de 2018. Regulamento técnico geral para fixação dos padrões de identidade e qualidade para polpa de fruta. Diário Oficial da República Federativa do Brasil, Brasília, DF, 8 out de 2018 Seção I, p. 23.
44. Aular, J.; Natale, W. Nutrição mineral e qualidade do fruto de algumas frutíferas tropicais: goiabeira, mangueira, bananeira e mamoeiro. *Rev. Bras. Frutic.* **2013**, 35, 1214-1231.
45. Prajapati, K.; Modi, H. A. The importance of potassium in plant growth – A review. *Indian J. Plant Physiol.* **2012**, 2, 177-186.
46. Heidari, M.; Jamshid, P. Interaction between salinity and potassium on grain yield, carbohydrate content and nutrient uptake in pearl millet. *J. Agric. Biol. Sci.* **2010**, 5, 39-46.
47. Garriga, M.; Retamales, J.B.; Bravo, S.R.; Caligari, P.D.S.; Lobos, G.A. Chlorophyll, anthocyanin, and gas exchange changes assessed by spectroradiometry in *Fragaria chiloensis* under salt stress. *J. Integr. Plant Biol.* **2014**, 56, 505-515.

 doi:10.20944/preprints202305.1079.v1

48. Araújo, P.G.L.; Figueiredo, R.W.; Alves, R.E.; Maia, G.A.; Moura, C.F.H.; Sousa, P.H.M. Qualidade físico-química e química de frutos de clones de aceroleira recobertos com filme de PVC e conservados por refrigeração. *Semin: Cienc. Agrar.* **2009**, 30, 867-880.
49. Adriano, E.; Leonel, S.; Evangelista, R. M. Qualidade de fruto da aceroleira cv. Olivier em dois estádios de maturação. *Rev. Bras. Frutic*. **2011**, VE, 541-545.