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Fruit quality of West Indian cherry under saline water irrigation and nitrogen-potassium fertilization[1]

Qualidade de frutos de aceroleira irrigada com águas salinas e adubação com nitrogênio-potássio

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HIGHLIGHTS:
The decrease in the size of West Indian cherry fruit reflects the diversion of energy to maintain metabolic activities.
The pH reduction is related to an increase in the total titratable acidity of West Indian cherry pulp.
Water salinity above 0.3 dS m^{-1} inhibits the synthesis of bioactive compounds in West Indian cherry fruits.

ABSTRACT: The presence of waters with high salt concentration stands out as a limiting factor for the quality of agricultural production. Thus, this study aimed to evaluate the fruit quality of West Indian cherry cv. Flor Branca, subjected to irrigation with water of different salinity levels and combinations of nitrogen-potassium fertilization, between 630 and 750 days after transplanting in the field. A randomized block design was used in a 5 × 4 factorial arrangement, with three replicates, whose treatments consisted of five values of electrical conductivies of irrigation water - ECw (0.3, 1.3, 2.3, 3.3 and 4.3 dS m^{-1}) and four combinations of nitrogen and potassium fertilization (70-50, 100-75, 130-100 and 160-125% of recommendation of N and K_2O, respectively). Electrical conductivity of irrigation water above 0.3 dS m^{-1} reduces the polar and equatorial diameters, hydrogen potential and flavonoid concentration and increases titratable acidity in West Indian cherry fruits. N-K_2O combination of 70/50% of fertilizer recommendation reduces the effect of salt stress of irrigation water on the anthocyanin concentration in the fruits at ECw of 1.3 dS m^{-1} and ascorbic acid at ECw of 3.3 and 4.3 dS m^{-1}.

Key words: *Malpighia emarginata* Sesse & Moc. ex DC., salt stress, plant nutrition, post-harvest

RESUMO: A presença de águas com elevados concentrações de sais se destaca como fator limitante da qualidade da produção agrícola. Assim, objetivou-se com este estudo avaliar a qualidade de frutos da aceroleira cv. Flor Branca, submetida à irrigação com diferentes níveis de águas salinas e combinações de adubação com nitrogênio-potássio, entre 630 e 750 dias após o transplantio a campo. Utilizou-se delineamento de blocos ao acaso em arranjo fatorial 5 × 4, com três repetições, cujos tratamentos foram cinco condutividades elétricas da água - CEa (0,3; 1,3; 2,3; 3,3 e 4,3 dS m^{-1}) e quatro combinações de adubação com nitrogênio e potássio: 70-50; 100-75; 130-100 e 160-125% da recomendação de N e K_2O, respectivamente. A CEa acima de 0,3 dS m^{-1} diminuiu o diâmetro polar e equatorial, potencial hidrogeniônico, teores de flavonoides e aumentou a acidez titulável nos frutos de aceroleira. A combinação de 70-50% da recomendação de N e K_2O, diminuiu o efeito do estresse salino da água de irrigação sobre o teor de antocianina nos frutos na CEa de 1,3 dS m^{-1}, e ácido ascórbico, nas salinidades de 3,3 e 4,3 dS m^{-1}.

Palavras-chave: *Malpighia emarginata* Sesse & Moc. ex DC., estresse salino, nutrição de plantas, pós-colheita

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Introduction

West Indian cherry (*Malpighia emarginata* Sesse & Moc. ex DC.) is commercialized in the form of frozen pulp and fresh fruit and enters the market of consumers who prefer natural juices, due to its high nutritional value, especially as a source of ascorbic acid, vitamin A, iron, calcium and B-complex vitamins: thiamine, riboflavin and niacin (Lima et al., 2014).

The semi-arid region of Northeast Brazil is characterized by irregular rains associated with high temperatures and evaporation, and part of sources that provide water for irrigation commonly have high levels of salts, which can compromise the quality and production of the crops (Melo et al., 2018).

In this context, several studies have been conducted aiming to promote the use of saline waters for the cultivation of West Indian cherry (Dias et al., 2018; Melo et al., 2018; Silva et al., 2019). However, there is no consensus on the threshold limit of soil and/or water salinity for the cultivation of this fruit species, and furthermore, in the literature, information about the effects of salt stress on the physicochemical characteristics of the fruits is incipient.

Increasing the supply of nutrients such as N and K to a salt-sensitive crop may increase its tolerance to salinity, since nitrogen plays a structural function, being part of several organic compounds vital to plants, such as amino acids, proteins, proline, among others (Guedes Filho et al., 2015). K participates in enzymatic activation, respiration, photosynthesis and improvement in water balance, as well as cationic competition with Na^+ (Almeida et al., 2017).

The objective of this study was to evaluate the fruit quality of West Indian cherry cv. Flor Branca, subjected to irrigation with saline waters and fertilization with different nitrogen-potassium percentages.

Material and Methods

The study was carried out under field conditions in the experimental area belonging to the Centro de Ciências e Tecnologia Agroalimentar (CCTA) of the Universidade Federal de Campina Grande (UFCG), Pombal, PB, Brazil, with location coordinates 6° 48' 16" S, 37° 49' 15" W and mean altitude of 144 m. The data of temperature (maximum and minimum), relative air humidity and precipitation collected during the experimental period are shown in Figure 1.

The experimental design was completely randomized blocks in a 5 x 4 factorial scheme, with three replicates, whose treatments consisted of different values of electrical conductivity of irrigation water - ECw (0.3; 1.3; 2.3; 3.3 and 4.3 dS m^{-1}), associated with four combinations of nitrogen (N) and potassium (K_2O) fertilization (70-50; 100-75; 130-100 and 160-125% of recommendation (Cavalcanti, 2008) of N and K_2O, respectively), using urea (45% N), monoammonium phosphate (12% N) and potassium chloride (60% K_2O) as sources of nitrogen and potassium. It is noteworthy that 98.79% (323.07 g) of the N requirement was met by urea and the complementation of 1.21% (3.93 g) with monoammonium phosphate.

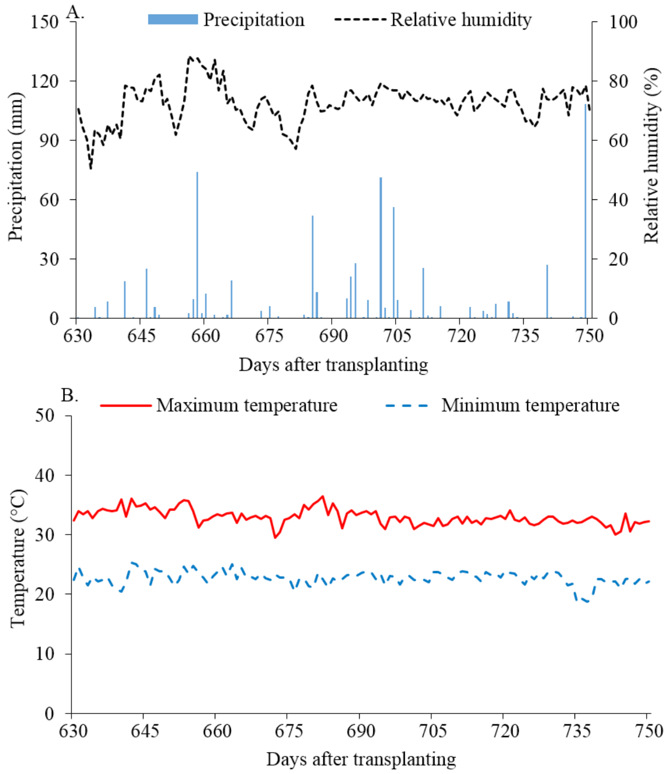


Figure 1. Data of mean precipitation and relative air humidity (A), mean minimum and maximum temperature (B) during the experimental period

The dose of 100% nitrogen and potassium based on the recommendation of fertilization for the irrigated cultivation of West Indian cherry cv. Flor Branca corresponded to 100 g of N and 80 g of K_2O per plant per year (Cavalcanti, 2008). The application of N and K doses started at 20 days after transplanting (DAT), applied simultaneously as topdressing via irrigation water with ECw of 0.3 dS m^{-1} for all treatments, in a circle, within a 20 cm radius in relation to the plant collar. The amounts of 100% N and K applied during the experiment (up to 750 DAT) corresponded to 327 g of N per plant + 261.81 g per plant of K_2O, being split into equal portions and applied every 15 days, in order to minimize the losses of N and K by volatilization and/or leaching.

In the filling of lysimeters, a dose of 20 g of P_2O_5 was incorporated into the soil in the form of single superphosphate (18% P_2O_5), equivalent to 111.91 g, recommended for the first year of cultivation of West Indian cherry cv. Flor Branca, according to the availability of phosphorus in the soil (Cavalcanti, 2008). Between 365 and 750 days after transplanting (DAT), phosphorus fertilization was applied as topdressing, using 20 g of P_2O_5 per plant, split into 12 applications in equal portions, at a 15-day interval, using monoammonium phosphate - MAP (61% P_2O_5 and 12% N), applied together with nitrogen and potassium fertilization of the treatments. The amount of nitrogen applied through MAP was subtracted from the doses of the treatments with nitrogen fertilization applied through urea.

Two weekly applications were performed with magnesium, sulfur and micronutrients through foliar spraying, using Quimifol Nutri® in the proportion of 0.5 g L^{-1}, as recommended by the manufacturer, and this product has in its composition:

2.5% magnesium, 6.0% sulfur, 2.0% boron, 0.5% copper, 0.3% molybdenum and 5.0% zinc.

The saline waters of treatments with ECw from 1.3 to 4.3 dS m^{-1} were prepared by adding to the municipal tap water of the municipality of Pombal, PB, Brazil (ECw of 0.3 dS m^{-1}) different amounts of NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$ salts, in the equivalent proportion of 7:2:1, which prevails in the main water sources available for irrigation in Northeastern Brazil, following the relationship between ECw and the concentration of salts ($mmol_c$ L^{-1} = EC x 10) (Richards, 1954) and the gram equivalent of each salt added to the water.

Irrigations, according to the respective treatments, began to be performed at 40 DAT, manually and every day, based on drainage lysimetry, with daily application of the volume of water to the soil of the containers to increase its moisture content to field capacity, determined by the difference between the volume of water applied in the previous irrigation and the volume drained. A leaching fraction of 0.15 was applied every 15 days, based on the total volume of water applied during this period, in order to reduce the excessive accumulation of salts in the soil.

West Indian cherry seedlings were produced in a commercial nursery registered at the National Registry of Seeds and Seedlings, located in the District of São Gonçalo, Sousa, PB, Brazil. The study was conducted using seedlings of West Indian cherry cv. Flor Branca with rootstock of the cv. Junco, grown in polyethylene bags with dimensions of 10 x 20 cm and volumetric capacity of 0.5 dm^3.

On the day before transplanting, the soil moisture content was increased to field capacity with tap water (ECw of 0.3 dS m^{-1}). Seedlings were transplanted to lysimeters (plastic containers) with a volume capacity of 60 L, at 120 days after grafting (DAG) on April 19, 2017, when they had 30 to 40 cm in height. The lysimeters received at the base a drainage system, composed of a drain with a diameter of 1/2" (12.7 mm), followed by a 3.0-cm-thick layer of crushed stone no. 1 and a 2.0-cm-thick layer of washed sand. Above the sand, the containers were filled with 56 L of soil classified as Fluvent collected in the 0-20 cm layer of Lot 14, Sector I, of the Irrigated Perimeter of Várzeas de Sousa, PB, Brazil, whose physical and chemical attributes (Table 1) were determined in the Irrigation and Salinity Laboratory of the Center for Natural Resources and Technology (CTRN/UFCG).

After transplanting, mulch of plant origin, composed of grass remains, was applied to minimize water losses by evaporation. Wooden rods were used as stakes with 80 cm height to attach the plants, so as to enable upright growth and avoid lodging. Formative pruning was carried out leaving a single stem, and its apical bud was pruned at 50 cm height. After the emergence of the lateral branches, a new pruning was carried out, leaving three lateral branches, distributed symmetrically in a spiral form, in the final 20 cm of the main stem. Corrective prunings were performed at 335 and 555 DAT as described by Silva et al. (2019).

Weeding operations were performed manually by eliminating (uprooting) weeds that appeared in the lysimeters, and using a motorized brush cutter in the rows and interrows of the crop. The moment of harvest was determined through visual analysis, and the fruits were harvested when they showed typical red color on the entire surface. To prevent the fruits from reaching an advanced stage of maturity and, consequently undergo loss in quality after harvest, the fruits were harvested at three days intervals.

The effect of treatments on the physicochemical composition was evaluated using 100 g of fruits per plant (around 32 fruits per plant) of harvests carried out between 630 and 750 DAT, when the following parameters were measured: polar diameter (PD, mm) and equatorial diameter (ED, mm) of fruits, hydrogen potential (pH), soluble solids (SS, °Brix) and titratable acidity (TA, %), contents of total soluble sugar (TSS, mg 100 g^{-1} of pulp), ascorbic acid (AA, mg 100 g^{-1} of pulp), flavonoids (FLA, mg 100 g^{-1} of pulp) and anthocyanins (ANT, mg 100 g^{-1} of pulp) of the pulp of West Indian cherry, cv. Flor Branca.

A digital potentiometer with a glass membrane electrode and resolution of 0.01 was used to determine pH. Soluble solids were expressed in °Brix and determined using a portable refractometer with resolution of 0.2. Titratable acidity was measured according to the standards of the Instituto Adolfo Lutz (IAL, 2008) and expressed as a percentage of citric acid.

The concentration of ascorbic acid was determined by titration, using 0.5 g of pulp, plus 49.5 mL of 0.5% oxalic acid and titrated against Tillmans' solution until appearance of pink color (IAL, 2008). Anthocyanin concentration were determined by the method of Sims & Gamon (2002). The concentration of flavonoids and anthocyanins were determined according to Francis (1982). Total soluble sugar concentration were determined using the anthrone reaction (Hodge & Hodfreiter, 1962).

The data were subjected to analysis of variance by the F test at p ≤ 0.05, and when significant, linear and quadratic

Table 1. Physical and chemical attributes of the soil used in the experiment

Textural class	AD (kg dm^{-3})	TP	OM	N	P assimilable (mg dm^{-3})	Exchange complex				
						Ca^{2+}	Mg^{2+}	Na^+	K^+	$H^+ + Al^{3+}$
		(%)				($cmol_c dm^{-3}$)				
SL	1.44	47.63	0.41	0.02	41.00	3.50	1.70	0.14	0.30	0.00
Saturation extract										
pH_{se}	EC_{se} (dS m^{-1})	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	SM (%)
		($mmol_c$ L)								
7.11	1.28	1.39	3.23	0.38	5.78	9.00	Absent	0.00	1.40	20.80
SAR (m mol $L^1)^{0.5}$		ESP			Salinity			Soil class		
3.80		2.48			Non saline-non sodic			Normal		

SL - Sandy loam; AD - Apparent density; TP - Total porosity; OM - Organic matter; pH_{se} - pH of the saturation extract, ECse -Electrical conductivity of the saturation extract at 25 °C; SM - Saturated soil moisture content (mass basis); SAR - Sodium adsorption ratio; ESP - Exchangeable sodium percentage; P, K^+ and Na^+ extracted with Mehlich-1; Ca^{2+} and Mg^{2+} extracted with 1.0 M KCl at pH 7.0; $H^+ + Al^{3+}$ extracted with 0.5 M CaOAc pH 7.0; OM: Walkley-Black Wet Digestion polynomial regression analysis was performed for the salinity levels and the mean comparison test (Tukey) was performed for nitrogen-potassium fertilization combinations, using the statistical program SISVAR/UFLA, version 5.6.

Results and Discussion

There was a significant effect ($p \leq 0.01$) of water salinity levels (SL) on polar and equatorial diameters, hydrogen potential (pH), soluble solids, titratable acidity, and flavonoids (Table 2). The NK combinations did not significantly influence ($p > 0.05$) any of these variables, and there was no significant interaction between the factors (SL x NK).

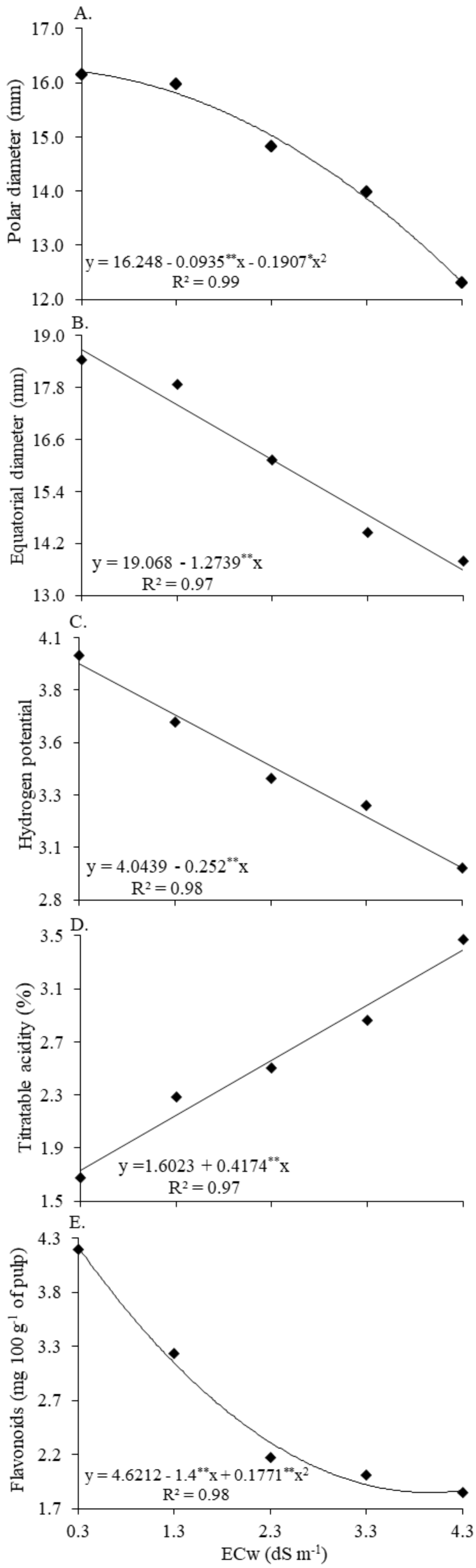
The polar diameter of the West Indian cherry fruits decreased in a quadratic way with the increase in the electrical conductivity of the water (Figure 2A). Plants grown under the lowest ECw level (0.3 dS m^{-1}) produced fruits with a larger polar diameter (16.20 mm), while plants under irrigation with water of 4.3 dS m^{-1} resulted in fruits with the smallest polar diameter (12.32 mm). Comparing the plants subjected to ECw of 4.3 dS m^{-1} in relation to those cultivated with water of 0.3 dS m^{-1}, a reduction in the polar diameter of 23.96% (3.88 mm) is observed. Water salinity linearly reduced the equatorial diameter of West Indian cherry fruits and, according to the regression equation (Figure 2B), there was reduction of 6.68%, per unit increment in ECw. Comparison of plants cultivated under water salinity of 4.3 dS m^{-1} with those irrigated using water with ECw of 0.3 dS m^{-1}, indicated a reduction of 27.27% (5.09 mm) in the equatorial diameter. The reduction in fruit size, observed in this study through polar and equatorial diameters, is the result of decreases in water potential and in water absorption by plants, in addition to interferences in photosynthetic efficiency, due to several factors, such as dehydration of cell membranes, toxicity by salts, reduction in CO_2 supply (due to stomatal closure), salinity-induced senescence and changes in enzymatic activity (Silva et al., 2020). Lima et al. (2020), while evaluating the effects of increasing irrigation water salinity (ECw from 0.6 to 3.8 dS m^{-1}) on the postharvest physicochemical composition of 'BRS 366 Jaburu' fresh fruits, noted that the increase in water salinity from 0.6 dS m^{-1} resulted in a decrease in the polar and equatorial diameters of the fruits.

The hydrogen potential of West Indian cherry pulp decreased linearly as a function of the increase in water salinity.

Table 2. Summary of the analysis of variance for polar diameter (PD), equatorial diameter (ED), hydrogen potential (pH), titratable acidity (TA) and flavonoids (FLA) of fruits of West Indian cherry cv. Flor Branca cultivated under irrigation with saline waters and fertilized with nitrogen-potassium

Source of variation	DF	Mean squares				
		PD	ED	pH	TA	FLA
Salinity levels (SL)	4	30.05^{**}	50.16^{**}	1.93^{**}	5.36^{**}	11.01^{**}
Linear regression	1	113.12^{**}	194.76^{**}	7.62^{**}	20.90^{**}	28.89^{**}
Quadratic regression	1	6.11^{*}	0.02^{ns}	0.02^{ns}	0.01^{ns}	10.06^{**}
NK combination (NK)	3	0.51^{ns}	2.54^{ns}	0.20^{ns}	0.25^{ns}	1.24^{ns}
Interaction (SL x NK)	12	0.75^{ns}	2.82^{ns}	0.34^{ns}	0.29^{ns}	0.93^{ns}
Blocks	2	0.55^{ns}	0.87^{ns}	0.71^{ns}	0.08^{ns}	1.11^{ns}
Residual		0.64	1.22	0.14	0.20	0.48
CV (%)		5.49	6.85	10.96	17.48	27.85

ns, **, * - Not significant, significant at $p \leq 0.01$ and at $p \leq 0.05$ by F test, respectively; DF - Degrees of freedom; CV - Coefficient of variation



** - Significant at $p \leq 0.01$

Figure 2. Polar (A) and equatorial diameter (B) of fruits, hydrogen potential (C), titratable acidity (D) and flavonoids (E) in the pulp of West Indian cherry cv. Flor Branca, as a function of electrical conductivity of irrigation water - ECw

According to the regression equation (Figure 2C), there was a reduction of 6.25% per unit increment in ECw. A reduction of 25.40% in pH was found between plants irrigated with ECw of 4.3 dS m^{-1} and those under water salinity of 0.3 dS m^{-1}. Although the pH of the West Indian cherry pulp was significantly reduced with the increase in water salinity, the values obtained in this study (ranging from 2.95 to 4.01) are considered adequate for West Indian cherry pulp quality standards, because the values are above the established minimum of 2.8 (Brasil, 2018).

In this study, the reduction of pH is directly related to the increase in the total titratable acidity (Figure 2D) of West Indian cherry pulp. Differently from what was observed in the present study, Bezerra et al. (2019) verified in a study with guava cv. Paluma that water salinity (ECw ranging from 0.3 to 3.5 dS m^{-1}) did not significantly interfere in pulp pH, in the first and second cycles of cultivation.

The increase in irrigation water salinity promoted a linear increase in the total titratable acidity of the pulp of West Indian cherry fruits. The regression equation (Figure 2D) showed an increase of 26.05% per unit increment in ECw. Plants irrigated with water of highest salinity level (4.3 dS m^{-1}) showed an increase of 96.64% compared to those that received the lowest level of ECw (0.3 dS m^{-1}). A similar effect with the increase in irrigation water salinity was also observed by Lima et al. (2020) on the pulp of West Indian cherry. According to the authors, this is related to changes in metabolic and physiological processes in plants caused by salt stress, which increases the synthesis of acids, with accumulation in the fruits.

The increase in titratable acidity in West Indian cherry pulp from the industrial point of view is important, as it reduces the need for the addition of acidifiers and results in improvement in nutritional quality, food safety and organoleptic quality, standing out as an important attribute for use in the juice industry and also for consumers of fresh fruit (Brasil et al., 2016).

The synthesis of flavonoids in West Indian cherry pulp was quadratically inhibited by irrigation water salinity. Based on the regression equation (Figure 2E), it can be noted that the maximum estimated value of this variable (4.194 mg 100 g^{-1} of pulp) was obtained in plants irrigated with ECw of 0.3 dS m^{-1}, with subsequent decrease until obtaining the minimum value of 1.850 mg 100 g^{-1} of pulp, due to irrigation using water with electrical conductivity of 4.3 dS m^{-1}, corresponding to a decrease of 55.89% (2.344 mg 100 g^{-1} of pulp), compared to those cultivated with the lowest salinity level (0.3 dS m^{-1}). Salt stress possibly acted in reducing the activity of the primary metabolism and, consequently, of the secondary metabolism, through which flavonoids are formed, resulting in inhibition of their synthesis (Borsatti et al., 2015).

According to the summary of the analysis of variance (Table 3), it was verified that the interaction between factors (SL x NK) was significant ($p \leq 0.01$) for the concentration of anthocyanins, soluble solids and ascorbic acid and significant ($p \leq 0.05$) for total soluble sugars. There were significant individual effects ($p \leq 0.01$) of water salinity and nitrogen/potassium fertilization combinations on the contents of anthocyanins and soluble solids, and effect of only water salinity ($p \leq 0.01$) on soluble sugars and ascorbic acid of West Indian cherry pulp.

In the follow-up analysis of the interaction between factors, it is possible to observe in Figure 3 the effect of the increase in water salinity for each combination of fertilization. It can be verified (Figure 3A) that there was a reduction in anthocyanin contents, with a better fit to the quadratic model as salinity increased, under the combination of 70-50% of the recommended dose of N-K, whose decreases were 4.05 mg 100 g^{-1} of pulp between plants irrigated under the highest salinity level (4.3 dS m^{-1}) and those that received ECw of 0.3 dS m^{-1}, while there was a decreasing linear effect caused by fertilization with the combinations of 100-75% of the recommended dose of N-K, with reductions of 6.84 per unit increase in the ECw level. However, there was no significant differences when plants were fertilized with the combination of 130-100% ($y = 1.8288 - 0.1093^{ns}x$, $R^2 = 0.50$) and 160-125% ($y = 1.6059 - 0.0463^{ns}x$, $R^2 = 0.10$) of recommendation of N-K.

Table 3. Summary of the analysis of variance for concentrations of anthocyanins (ANT), soluble solids (SS), total soluble sugars (TSS) and ascorbic acid (AA) in the pulp of West Indian cherry cv. Flor Branca cultivated under irrigation with saline waters and nitrogen-potassium combinations

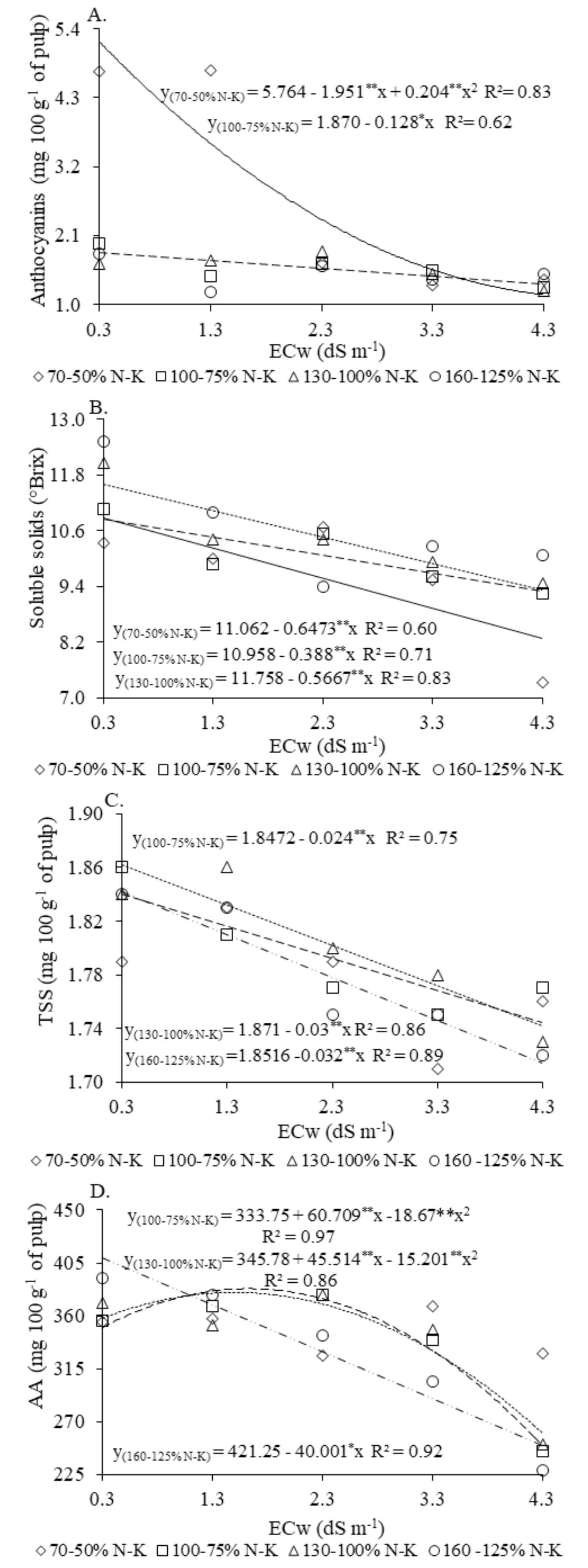
Source of variation	DF	Mean squares			
		ANT	SS	TSS	AA
Salinity levels (SL)	4	3.33^{**}	9.60^{**}	0.02^{**}	22710.39^{**}
Linear regression	1	12.57^{**}	35.20^{**}	0.07^{**}	66213.61^{**}
Quadratic regression	1	0.36^{ns}	0.14^{ns}	0.0004^{ns}	20279.62^{**}
NK combination (NK)	3	2.02^{**}	1.59^{**}	0.002^{ns}	800.81^{ns}
Interaction (SL x NK)	12	3.19^{**}	1.91^{**}	0.001^{*}	2616.68^{*}
Blocks	2	0.58^{ns}	0.20^{ns}	0.0007^{ns}	1006.65^{ns}
Residual		0.23	0.10	0.0009	656.03
CV (%)		26.01	3.24	1.68	7.57

ns, **, * - Not significant, significant at $p \leq 0.01$ and at $p \leq 0.05$ by F test, respectively; DF - Degrees of freedom; CV - Coefficient of variation

Probably, the decrease in anthocyanin concentration occurred due to the reduction of flavonoids in fruits as salinity of irrigation water increased, since anthocyanins are compounds that belong to the flavonoid class and are responsible for the red color of ripe West Indian cherry, an important aspect of commercial interest (Maciel et al., 2010). According to Araújo et al. (2009), the higher the anthocyanin content, the better the consumer's acceptance of the product. The highest values in the present study were observed using the combination of 70-50% of the recommended dose of N-K at the ECw of 0.3 dS m^{-1}.

For soluble solids concentration (Figure 3B), there were linear reductions of 5.85, 3.54, and 4.81% per unit increase in ECw under the combinations of 70-50, 100-75 and 130-100% of recommendation of N-K, respectively. The data of plants fertilized with 160-125% did not obtain an adequate fit to the tested models ($y = 11.954 - 0.5653^{ns}x$, $R^2 = 0.56$). Although there was a decrease in the soluble solids contents in the fruits as water salinity increased (Figure 3B), the lowest values of °Brix (8.28, 9.29, 9.32 and 9.52 under the combinations of 70-50, 100-75, 130-100 and 160-125% of recommendations of N-K, respectively) were obtained at the highest level of water salinity (4.3 dS m^{-1}), and all except the 70-50 combination led to values higher than the value of 8.7 °Brix found in mature fruits of West Indian cherry cv. Flor Branca (Silva et al., 2020).

The values of total soluble sugars (Figure 3C) of West Indian cherry plants fertilized with 70-50% of the N-K recommendation showed relatively low value of determination coefficient of the fitted regression model ($y = 1.8174 - 0.018^{ns}x$,



*, ** - Significant at $p \leq 0.01$ and at $p \leq 0.05$ by F test, respectively

Figure 3. Effect of irrigation water salinities and combination of NK fertilization on the concentrations of anthocyanins (A), soluble solids (B), total soluble sugars - TSS (C) and ascorbic acid - AA (D) in the pulp of West Indian cherry cv. Flor Branca

$R^2 = 0.41$). However, plants subjected to 100-75, 130-100 and 160-125% of N-K linearly reduced their values of total soluble sugars, with decreases of 1.29, 1.60 and 1.72% per unit increment in water salinity, respectively. According to Brasil et al. (2016), higher contents of sugars in fruits are preferred for fresh consumption and industrialization, because these sugars give the product a sweeter flavor and enable an increase in viscosity and improvement in texture, besides assisting in the reduction of the freezing point.

The decrease in the contents of soluble solids and total sugars in the pulp of West Indian cherry fruits as salinity increased, in plants fertilized with the different combinations of fertilization, can be associated with the increase in Na^+ and Cl^- contents in leaf tissues, which modified the biochemical processes and physiology of West Indian cherry plants as a result of salt stress. This resulted in changes in photosynthetic activities and in the rate of translocation of assimilates, which may have negatively influenced the accumulation of sugars in fruits (Taiz et al., 2017). Decreases in soluble solids contents were also observed in yellow passion fruit (Dias et al., 2011) and tomato (Paiva et al., 2018) fruits subjected to increase in irrigation water salinity.

Regarding ascorbic acid (Figure 3D), it was verified that the contents were not influenced by the linear coefficient of regression equation (ECw) for the combination of 70-50% N-K recommendation ($y = 356.99 - 4.352^{ns}x$ $R^2 = 0.13$). However, there was a significant effect, with quadratic response, under the use of combinations of 100-75 and 130-100% of the recommended dose of N-K, whose highest values (383.10 and 379.85 mg 100 g^{-1} of pulp, respectively) were obtained at the ECw of 1.6 dS m^{-1}. In plants fertilized with the highest combination of fertilization (160-125% of N-K recommendation), the ascorbic acid content in the fruits was linearly reduced by 9.50% per unit increase in ECw.

The concentrations of ascorbic acid (Figure 3D) obtained in this study are not in accordance with the recommendations of the Ministry of Agriculture, Livestock and Supply through Normative Instruction No. 49, of September 26, 2018 (Brasil, 2018), which establishes the quality standard for West Indian cherry fruits for processing and marketing the pulp and considers 800 mg 100 g^{-1} as an adequate concentration. In this context, it is noteworthy that, regardless of the treatments tested, there was a decrease in the concentration of ascorbic acid in the West Indian cherry fruits.

These results show that the use of the combinations of 100-75 and 130-100% of N-K recommendation mitigated the negative effects of increasing salinity up to the ECw of 1.6 dS m^{-1} for this variable, promoting greater synthesis of hexose sugars, specifically D-glucose or D-galactose, from which ascorbic acid is synthesized in the fruits (Dias et al., 2011). On the other hand, the drastic reduction of ascorbic acid content due to the use of the highest doses of N-K (160-125%) may have resulted from the increase in salt stress in the root zone of West Indian cherry plants, due to the high salt indices of the fertilizers used as sources of N (urea) and K (potassium chloride), corresponding to 75 and 116%, respectively (Silva et al., 2019).

In the follow-up analysis of the interaction between the factors in Figure 4, it is possible to observe the effect of the different fertilization combinations at each level of irrigation water salinity. Significant difference was observed in anthocyanin content (Figure 4A), and the highest contents of anthocyanin were obtained in plants that received the combination of 70-50% of N-K recommendation under ECw of 0.3 and 1.3 dS m^{-1}. According to Dionisio et al. (2016), several factors contribute to the reduction of bioactive compound contents, especially temperature, exposure to light and oxygen, and pH of the medium.

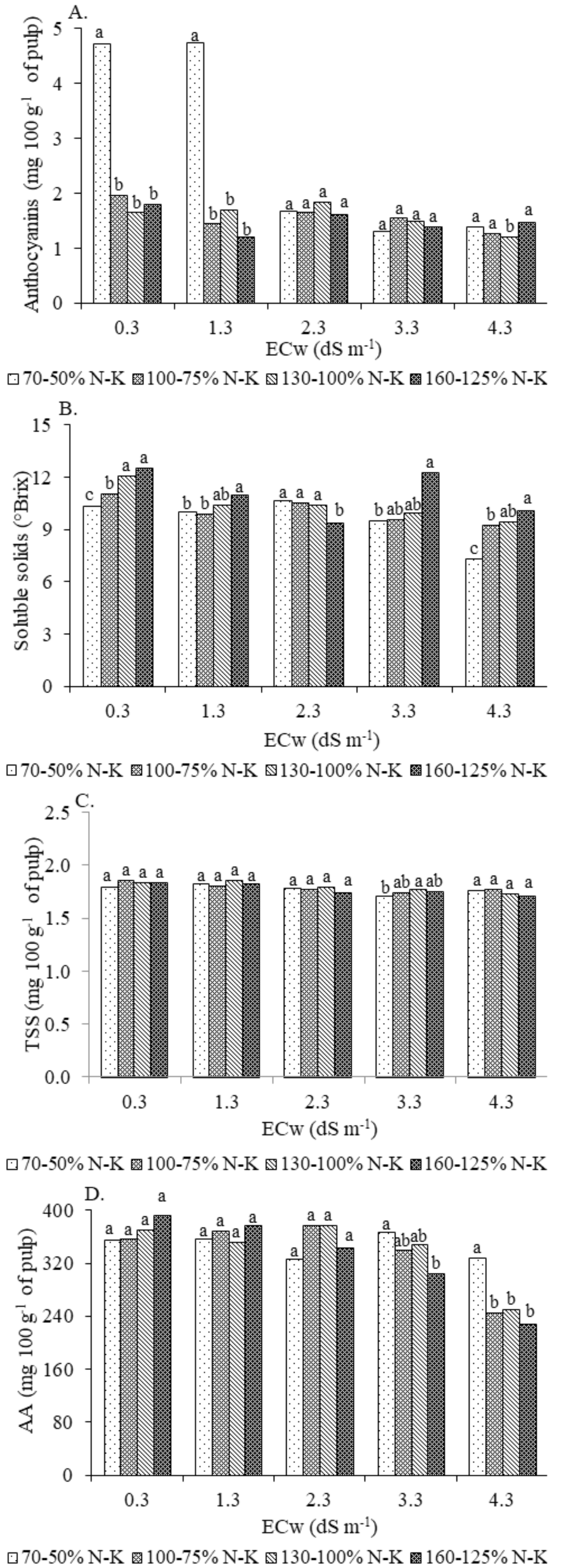
As for soluble solids, it is verified (Figure 4B) that plants irrigated with ECw of 0.3 dS m^{-1} and fertilized with the combination 160-125% of N-K recommendation obtained statistically higher SS contents than those that received the combinations of 70-50 and 100-75% of N-K recommendation, while for plants grown under ECw of 1.3, 3.3 and 4.3 dS m^{-1}, fertilization with 160-125% recommendation of N-K resulted in higher soluble solids contents. Soluble solids in West Indian cherry pulp stand out as an indicator of sweetness and, consequently, of quality, in terms of fruit flavor, which is mainly attributed to the increase in sucrose concentration in fruit pulp (Barros et al., 2012).

According to the Ministry of Agriculture, Livestock and Supply through Normative Instruction No. 49, of September 26, 2018 (Brasil, 2018), the minimum content of soluble solids established for commercialization as pulp is 5.5 °Brix. Thus, the values obtained for the West Indian cherry fruits in this study (on average 10.28 °Brix) are in accordance with the quality standard for processing and marketing the pulp. Thus, the increase in the synthesis of soluble solids in the pulp of West Indian cherry due to the greater availability of N-K is understandable, given the functions performed by these nutrients in metabolic reactions, participating in the synthesis and translocation of carbohydrates and proteins, resulting in the increase of soluble solids (Takahashi et al., 2018).

Barros et al. (2012) concluded that nitrogen fertilization positively influences the soluble solids contents of watermelon. Carneiro et al. (2018) evaluated the quality of mango fruits under potassium fertilization and concluded that the soluble solids content of the fruit increased with the use of adequate potassium dose.

The total soluble sugar contents of the pulp of West Indian cherry grown under irrigation water electrical conductivity of 0.3, 1.3, 2.3 and 4.3 dS m^{-1} were not significantly affected by the use of the different NK combinations (Figure 4C), except in plants grown under ECw of 3.3 dS m^{-1} and fertilized with 130-100% N-K, in which the TSS contents were statistically higher in comparison to those that received the combination of 70-50% of N and K. This phenomenon is associated with the function of the N and K used through the highest doses, in the synthesis of soluble sugars, as also observed for the higher soluble solids contents (Figure 3) in the fruits of plants that received this level of water salinity.

For the ascorbic acid concentration (Figure 4D), there was a significant effect of the N-K combinations only in plants that were irrigated with high ECw (3.3 and 4.3 dS m^{-1}). At these salinity levels, the highest value of ascorbic acid was obtained when plants were fertilized with N-K combination of 70-50% differing statistically from the other combinations under ECw of 4.3 dS m^{-1} and 160-125% N-K combination under ECw of



Bars with different letters indicate a significant difference between treatments by Tukey test ($p \leq 0.05$)

Figure 4. Effect of fertilization combination - N-K (%) at each electrical conductivity of irrigation water - ECw on the concentrations of anthocyanins (A), soluble solids (B), total soluble sugars - TSS (C) and ascorbic acid - AA (D) in the pulp of West Indian cherry cv. Flor Branca

3.3 ds m^{-1}. The reduction in ascorbic acid content of West Indian cherry pulp as a function of increasing water salinity may be related to changes in photosynthetic activities and translocation of photoassimilates resulting from the stress caused by excess salts in irrigation water. Bezerra et al. (2019) also found that the increase in the electrical conductivity of irrigation water (ECw from 0.3 to 3.5 dS m^{-1}) resulted in a decrease in ascorbic acid content in 'Paluma' guava fruits. According to Dias et al. (2011), the reduction in ascorbic acid content may be related to the inhibition in the synthesis of hexose sugars, originally D-glucose or D-galactose.

Conclusions

1. Irrigation water salinity above 0.3 dS m^{-1} negatively affects the physicochemical characterization of West Indian cherry fruits, between 630 and 750 days after transplantation, causing reduction in polar and equatorial diameters, hydrogen potential and flavonoid concentration and increase in total titratable acidity.

2. The combination of 70-50% recommendation of N and K_2O reduces the effect of salt stress of irrigation water on the anthocyanin concentration of fruits in plants grown with irrigation water salinity of 1.3 dS m^{-1} and on ascorbic acid concentration at the irrigation water salinity of 3.3 and 4.3 dS m^{-1}.

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