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QUALIDADE DA BERINJELA IRRIGADA COM ÁGUAS SALOBRAS VIA GOTEJAMENTO CONTÍNUO E POR PULSOS

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1 RESUMO

Devido suas propriedades medicinais e por ser um alimento rico em antioxidantes, o consumo da hortaliça berinjela vem crescendo. Durante o cultivo da berinjela, o manejo da água e do solo são fatores que podem influenciar a qualidade do fruto. Assim, objetivou-se com este trabalho analisar as características físico-químicas do fruto da berinjela ‘Florida Market’ irrigada com águas salobras por gotejamento contínuo e pulsos. O experimento foi conduzido em ambiente protegido com delineamento experimental em blocos casualizados, em esquema fatorial 2 x 4, com cinco repetições. Os tratamentos consistiram de duas formas de aplicação de água: gotejamento contínuo e pulsos, com quatro níveis de condutividade elétrica da água – CEa (0,3 (controle); 1,5; 3,0 e 4,5 dS m^{-1}). Foram avaliadas as variáveis: massa fresca do fruto, teor de sólidos solúveis totais, pH da polpa, acidez total titulável e relação sólidos solúveis totais/acidez total titulável. Com o incremento da salinidade da água de irrigação o teor de sólidos solúveis totais (+3,60%) e acidez total titulável (+9,87%) aumentaram, enquanto a relação de sólidos solúveis totais/acidez total titulável (-4,53%) e a massa fresca do fruto diminuíram. A interação entre a salinidade e a forma de aplicação da água não influenciou as características físico-químicas do fruto.

Palavras-chave: *Solanum melongena* L., salinidade, sólidos solúveis, acidez titulável.

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QUALITY OF EGGPLANT FRUIT IRRIGATED WITH BRACKISH WATER UNDER CONTINUOUS DRIP AND PULSE IRRIGATION

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2 ABSTRACT

Due to its medicinal properties and to be a functional food rich in antioxidants, the eggplant vegetable consumption has been increasing. During eggplant cultivation, water and soil management are factors that can influence fruit quality. Therefore, this work aimed to analyze the physico-chemical characteristics of the fruit of the eggplant ‘Florida Market’ irrigated with brackish water under continuous drip and pulse irrigation. The experiment was conducted in protected environment in a randomized block design, adopting a 2 x 4 factorial scheme, with five replicates. The treatments consisted of a combination of two forms of application of brackish water: continuous drip and pulses, with four levels of water salinity - ECw (0.3 (control); 1.5; 3.0 and 4.5 dS m^{-1}). The variables evaluated were fresh weight of the fruit, total soluble solids content, pH of the pulp, total titratable acidity and the ratio of total soluble solids/total titratable acidity. With the increase in salinity of irrigation water the content of total soluble solids (+3.60%) and total titratable acidity (+9.87%) increased, while the ratio of total soluble solids/total titratable acidity (-4.53%) and fresh fruit mass decreased. The interaction between salinity and the form of water application did not influence the physico-chemical characteristics of the fruit.

Keywords: *Solanum melongena* L., salinity, soluble solids, titratable acidity.

3 INTRODUCTION

Eggplant (*Solanum melongena* L.) is an economically important species of the Solanaceae family that results in high yields and good adaptation to hot and humid environments (GÜRBÜZ et al., 2018). It is present in the diet of millions of people in drought-affected regions of the world (WAKCHAURE et al., 2020). Globally, eggplant production is approximately 35.3 million tons, accounting for an area of 1.9 million hectares (ÇOLAK et al., 2018).

The demand for natural products to combat various diseases has stimulated the use of foods rich in bioactive compounds. In this context, the market share of eggplant has increased due to its medicinal properties, including antioxidant, anti-inflammatory, cardioprotective, antiobesity, anticancer, cholesterol-lowering, and a source of vitamins and minerals (GÜRBÜZ et al., 2018). In eggplant cultivation, water deficit is particularly detrimental during the flowering and fruiting stages. Water deficiency at these stages can degrade fruit quality, as it can favor malformation and promote unevenness, blossom-end rot, and a bitter taste (MAROUELLI et al., 2014). According to Wakchaure et al. (2020), water stress reduces the average length, shape, and weight of eggplant fruit, in addition to decreasing flesh firmness. Therefore, irrigation is essential for eggplant cultivation, especially in arid and semiarid climate regions.

Owing to its greater efficiency, localized continuous drip irrigation is the most suitable method for eggplant cultivation, as it has the advantage of reducing the occurrence of aerial diseases, as it does not wet the plant's leaves, and it also limits evaporation and water drainage, in addition to promoting high water use efficiency and increased fruit quality (MAROUELLI et al., 2014; ÇOLAK et al., 2018).

In pulse irrigation, the water depth is fractionated. During irrigation depth application, there are alternating periods of water application and rest (ALMEIDA et al., 2018). Therefore, in some crops, this technique provides greater savings and efficiency in terms of water use and a greater volume of wet soil within the root zone. It also delays the negative effects of using brackish water, in addition to helping to increase fruit quality, ripeness, and vitamin C content (ELNESR et al., 2015; ALMEIDA et al., 2018). When total production is compared with commercial production, pulse irrigation, compared with continuous drip irrigation, can result in less fruit loss in eggplant crops (ARRIERO et al., 2020).

In Brazil, the semiarid region uses water with high salt concentrations, including groundwater, for vegetable production (SILVA et al., 2015). However, soil and/or water salinity is the main abiotic stress factor in eggplant plants, as it promotes changes in membrane integrity and limits plant growth and productivity (LIMA et al., 2015; RAJESHWARI; BHUVANESHWARI, 2017). However, salt tolerance is a characteristic that varies according to plant type, and the use of species or cultivars adapted to saline conditions is a good strategy for improving food production (PEDROTTI et al., 2015).

According to Lima et al. (2015), the eggplant ' Ciça ' is classified as sensitive to irrigation water salinity, presenting a 13.5% reduction in fruit production per unit increase in irrigation water electrical conductivity above 0.5 dS m^{-1}. Additionally, according to the authors, saline stress significantly reduces the translocation of photoassimilates to eggplant fruits, which may be related to lower water and nutrient absorption. Thus, the main challenge in increasing crop growth and productivity is the use of the best brackish water management strategy (LI et al., 2019). This condition can also interfere with fruit quality parameters (SANTOS, 2018; LI et al., 2019).

The postharvest quality of eggplant can be influenced by soil (RADICETTI et al., 2016) and water (WAKCHAURE et al., 2020) management. For tomato, which belongs to the same family as eggplant (Solanaceae), fruit quality varies according to the environmental conditions, crop management practices adopted (PAIVA et al., 2018) and irrigation strategies with brackish water (LI et al., 2019).

In this context, the objective of the present work was to analyze the physicochemical characteristics of eggplant fruit irrigated with brackish water via continuous drip and pulses.

4 MATERIALS AND METHODS

The experiment was conducted in a protected environment in the experimental area of the Water and Soil Engineering Center of the Federal University of Recôncavo da Bahia, Cruz das Almas (BA), from April to July 2019. The coordinates of the protected environment are 12°40'39” South latitude and 39°40'23” West longitude of Greenwich with an altitude of 220 m. The average air temperatures inside the greenhouse during the experimental period varied between 24.8 and 25.2°C, and the average relative humidity was 79%.

The experimental design was randomized blocks in a 2 × 4 factorial scheme with five replications, totaling 40 experimental units. Two forms of water were applied: continuous drip (G) and pulsed (P), with four levels of electrical conductivity of the irrigation water (ECa) of 0.3 dS m^{-1} (control - supply water), 1.5, 3.0 and 4.5 dS m^{-1}. Brackish water was prepared by adding sodium chloride (NaCl) without iodine to the local water supply (ECw = 0.3 dS m^{-1}) on the basis of the empirical relationship ECw = 10 × $mmol_c$ L^{-1}. After preparation, the ECw values were measured with a portable digital meter.

'Florida Market' eggplant seedlings were grown in 50-cell polyethylene trays containing coconut fiber and worm castings at a 2:1 (v/v) ratio. The plants were transplanted 30 days after sowing, at which point the plants had four permanent leaves.

The experimental unit consisted of a 100 L container filled with a 0.05 m layer of gravel and approximately 150 kg of soil from the 0–0.20 m layer of the experimental area of the Graduate Program in Agricultural Engineering. The soil, classified as a typical Dystrocohesive Yellow Latosol (SANTOS et al., 2018), was properly broken, homogenized, and previously characterized (Table 1) following the methodologies recommended by Teixeira et al. (2017). The gravel layer and soil were separated by a screen. A 16 mm hose was installed at the bottom of each container for drainage.

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

Physical characteristics							
CC	PM	Sand	Silt	Clay	Texture	MO	DS
---cm^3 cm^{-3} ---		------- g kg^{-1} -------				g kg^{-1}	kg dm^{-3}
0.451	0.185	682.5	202.2	115.3	Sandy loam	1.18	1.5

Chemical characteristics											
CEes	pH	P	K	Her e	Mg	Al	H+Al	In the	SB	CTC	V
dS m^{-1}		mg dm^{-3}		-------------------- cmol $_c$ dm^{-3} --------------------							%
1.28	5.1	1.3	48	1.0	0.5	0.2	3.0	0.04	1.66	4.66	35.6

CEes – Electrical conductivity of soil saturation extract; SB – Sum of bases; V – Base saturation; CC – Water content at field capacity; PM – Water content at permanent wilting point; MO – Organic matter; DS – Soil bulk density

Liming and fertilization were calculated according to the chemical analysis of the soil (Table 1) and considering the reservoir area (0.5 ^{m2}). Liming was performed 60 days before transplanting by adding 65 g of dolomitic limestone per reservoir (150 kg of soil) to increase the base saturation to 70% (TRANI, 2014). Planting fertilization was performed by applying 46 g of monoammonium phosphate - MAP (10% N and 48% P_2O_5) and 13 g of potassium chloride - KCl (60% K_2O) per box. Following the recommendations for the crop proposed by Trani (2014), 3.3 g of urea (45% N) and 2.5 g of KCl were applied as top dressing per container in three different periods: 30, 60 and 90 days after transplanting (DAT).

The irrigation system adopted was a continuous drip and pulse irrigation system. One conventional emitter was used per container, with a flow rate of 2.1 L h^{-1} and a Christiansen uniformity coefficient of 91%. These values were obtained prior to the start of the experiment through testing. The emitters were connected to 5 mm microtubes and 20 mm polyethylene tubing. Water was applied in pulses as follows: after the irrigation time was determined, it was divided into six pulses, with a 30-min interval between pulses. A digital controller with four outputs and 24 programs, divided into six pulses, was used to control the pulses.

For irrigation management, a tensiometer was installed in three replicates of each treatment at a depth of 0.15 m. The tensiometer reading was taken daily, and irrigation was carried out with the aim of increasing moisture to a field capacity of 10 kPa when the average soil water tension reached 15 kPa.

The calculation of the applied water depth was carried out according to the characteristic curve of water retention in the soil, which was obtained according to the van Genuchten model (1980) presented in equation (1).

$$\theta = 0{,}101 + \left(\frac{0{,}486-0{,}101}{\left[1+(0{,}056\ |\Psi|)^{1{,}345}\right]^{0{,}256}}\right) \quad (1)$$

where:
θ - soil moisture ($cm^3\ cm^{-3}$); and
Ψ - matrix potential (kPa).

Fruit harvests were performed after 70 DAT, with all fruits being harvested. The average fresh mass (FM) of the collected fruits was determined via a digital scale (0.001 g precision). The final harvest was performed at 100 DAT, in which one fruit (the best) from each replicate per treatment (totaling 40 fruits) was selected for physicochemical characterization. Commercial-quality fruits with bright purple coloration, soft and firm flesh, and a green calyx were selected. After selection, the fruits were wrapped in two layers of polyvinyl chloride (PVC) film, placed in labeled transparent bags, and finally stored in a freezer at -10 °C until samples were collected for analysis.

On the day of analysis, the fruits were mechanically processed to perform the following physicochemical analyses: total soluble solids content (TSS) – determined with the aid of a portable refractometer RHB 32 ATC and the results obtained in °Brix; pH – determined with the aid of a digital pH meter model HANNA HI 4222, previously calibrated with buffer solutions of pH 4.0 and 7.0; total titratable acidity (TTA) – results expressed in g of citric acid per 100 g of pulp – for determination, five grams of crushed fruit were used, diluted with distilled water, obtaining a sample with a volume of 25 mL and titrated with a standard NaOH solution (0.01 N), using phenolphthalein as an indicator, according to the methodology described by Zenebon, Pascuet and Tiglea (2008); and the SST/TTA ratio was obtained by dividing the two variables.

The data obtained were subjected to analysis of variance, and when significant, the F test was used. The means were compared via Tukey's test at the 0.05 probability level for the different irrigation methods. Factors related to salinity levels, in the case of a significant effect, were statistically analyzed via polynomial regression (linear and quadratic). All the statistical analyses were performed via the Sisvar statistical program, version 5.6 (FERREIRA, 2019).

5 RESULTS AND DISCUSSION

For the average fresh mass of fruits (MF), total soluble solids content (TSS), total titratable acidity (TTA) and the TSS/TTA ratio, significant effects ($p<0.01$) of irrigation water salinity were observed, whereas no influence of irrigation method or interaction of factors was observed for any of these variables or pH (Table 2).

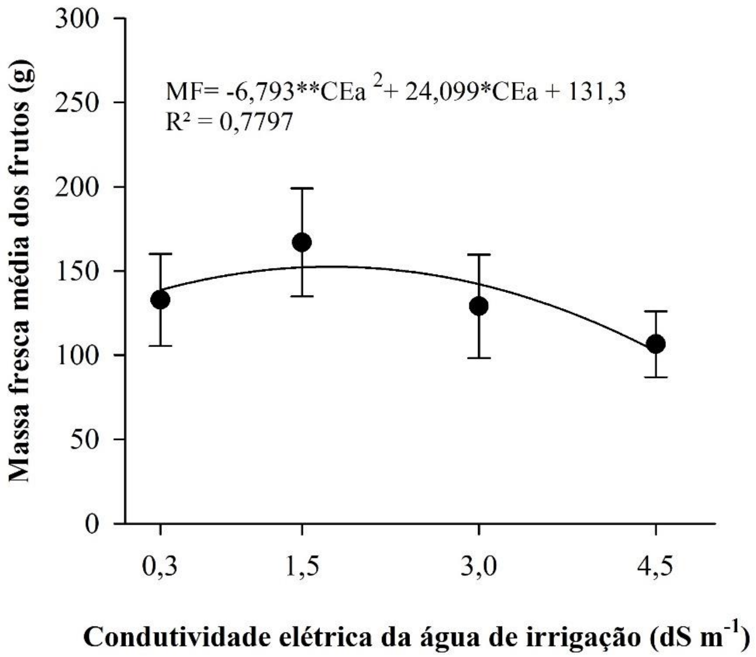
Table 2. Summary of analysis of variance for mean fruit fresh mass (MF, g), pH, total soluble solids (TSS, °Brix), total titratable acidity (TTA, g citric acid 100 g $^{-1}$) and the TSS/TTA ratio of 'Florida Market' eggplant grown in a protected environment with continuous drip and pulse irrigation under saline stress

Source of Variation	GL	Mean square				
		MF	pH	SST	ATT	SST/ATT
Irrigation (I)	1	0.893 ^{ns}	0.016 ^{ns}	1.17 ^{ns}	0.0002 ^{ns}	52.91 ^{ns}
Salinity (S)	3	486,075**	0.014 ^{ns}	1.61**	0.001**	387.91**
Linear	1	1122.769 ^{ns}	0.035 ^{ns}	3,987**	0.002**	1046.29**
Quadratic	1	198,072**	0.0003 ^{ns}	0.014 ^{ns}	0.0005 ^{ns}	97.02 ^{ns}
Interaction (I x S)	3	150.283 ^{ns}	0.09 ^{ns}	0.019 ^{ns}	0.0004 ^{ns}	146.28 ^{ns}
Residue	28	219.61	0.011	0.281	0.0003	76.87
CV (%)		22.75	2.24	8.80	19:00	13.71
Average		126.04	4.63	6.03	0.098	63.96

* and ** indicate significance at $p<0.05$ and $p<0.01$, respectively; ^{ns} – not significant ($p>0.05$) according to the F test

Figure 1 shows that the salinity of the irrigation water influenced the MF quadratically, with the highest estimated value (152.69 g) under a CEa of 1.77 dS m $^{-1}$. When comparing the supply water (CEa = 0.3 dS m $^{-1}$) with the highest salinity level studied (CEa = 4.5 dS m $^{-1}$), we observed a reduction in MF of 25.9%.

Figure 1. Average fresh mass of 'Florida Market' eggplant fruits as a function of the electrical conductivity of irrigation water grown in a protected environment under continuous drip and pulse irrigation.



*, ** - significant at p < 0.05 and 0.01, respectively; vertical bars represent the standard deviation (n=5).
Source: Irriga (2021)

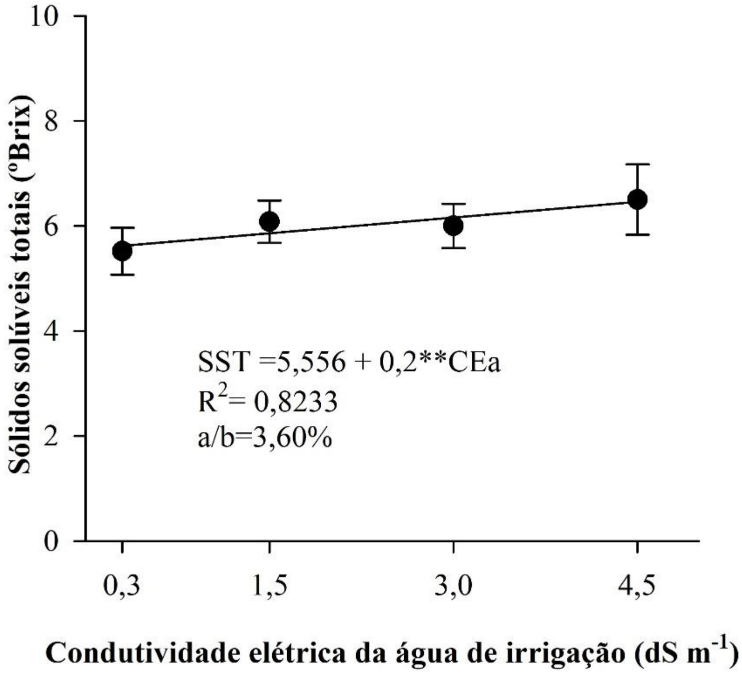
' Ciça ' eggplant irrigated with brackish water ranging from 0.5 to 5.0 dS m $^{-1}$, Santos (2018) reported a linear reduction of 4.91% per unit increase in water salinity, with the MF being lower than 170 g. Costa et al. (2019) cultivated 'Florida Market' eggplant and observed MF values ranging from 196.67 to 281.67 g under three cultivation forms: conventional, organic and hydroponic. Arriero et al. (2020), using 'Florida Market' eggplant in soil irrigated via drip and pulses with supply water (CEa = 0.3 dS m $^{-1}$) and brackish water (CEa = 2.5 dS m $^{-1}$), reported MF values higher than those reported in the present work. However, these authors did not observe any significant difference between the irrigation methods or the salinity of the water used.

The reduction in FM may be associated with increased energy expenditure by the plant to maintain metabolic activities due to the salinity stress to which it was subjected. Furthermore, salinity decreases chlorophyll and increases damage to cell membranes, disrupting physiological and biochemical processes considered essential for the salinity tolerance mechanism in eggplant plants (RAJESHWARI; BHUVANESHWARI, 2017). Thus, salinity affects plant growth, especially eggplant fruit growth, as reported by Lima et al. (2015), when the partitioning of dry matter into different parts of a plant is analyzed.

Notably, the pH variable had no significant effect on any of the factors studied (Table 2). The average pH value (4.63) observed in the present study, although lower than that reported by Oliveira et al. (2019) for ' Ciça ' eggplant, is in accordance with Oliveira et al. (2016), who reported that acidic pH (pH <5.0) is a key factor for conservation, since it acts as an inhibitor of the growth of microorganisms, a desirable characteristic during postharvest.

With respect to the TSS content, a linear regression was observed, with an increase of 3.6% per unit increase in ECw (Figure 2). The lowest TSS value (5.62 °Brix) was observed when supply water was used (ECw = 0.3 dS m $^{-1}$), with a value of 6.46 °Brix under an ECw of 4.5 dS m $^{-1}$. These results corroborate those of Santos (2018), who, working with eggplant irrigation with brackish water, reported that the total soluble solids content increased when water with an electrical conductivity of up to 2.59 dS m $^{-1}$ was used. Li et al. (2019) also reported an increase in the TSS content in tomato crops when saline water was used compared with when low-salinity water was used.

Figure 2. Average content of total soluble solids as a function of the electrical conductivity of the irrigation water in the fruits of 'Florida Market' eggplants grown in a protected environment under continuous drip and pulse irrigation.



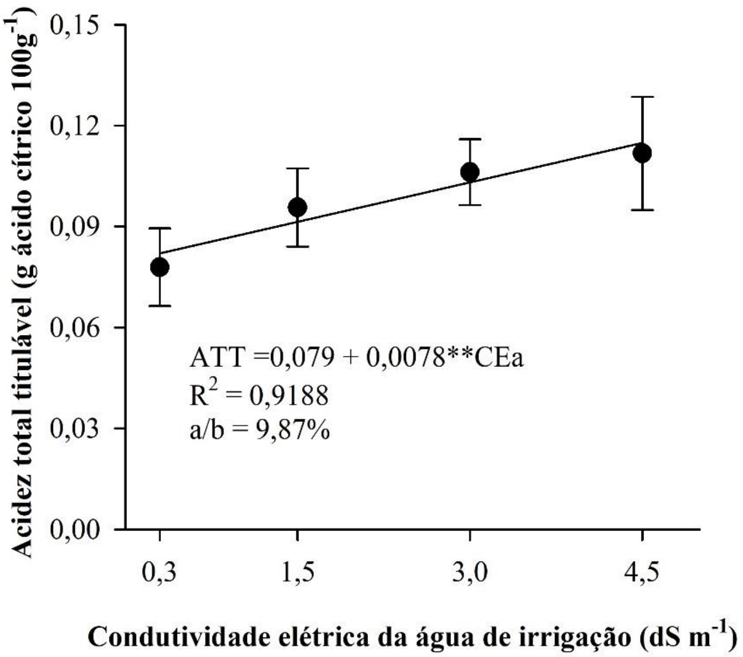
** - significant at $p < 0.01$; vertical bars represent standard deviations (n=5)
Source: Irriga (2021)

The values reported in the present study were higher than those reported in other studies with eggplant. For example, Radicetti et al. (2016) reported soluble solids contents ranging from 3.57 to 3.97 °Brix under different soil management practices, Çolak et al. (2018) reported contents ranging from 4.38 to 4.55 °Brix for eggplant via surface drip and different irrigation regimes, whereas Salas et al. (2020) studied two eggplant cultivars ('Casino' and 'Morena') under different levels of chicken manure and reported values of 2.78 and 2.59 °Brix, respectively. These differences in the studies may be related to the growing conditions and/or the cultivars used.

The increase in total soluble solids content is related to the amount of sugars and, consequently, to the flavor of the fruits, thus conferring better quality to the product (CHITARRA; CHITARRA, 2005). According to Wakchaure et al. (2020), the increase in TSS in *S. melongena* ' Panchganga ' may result from the conversion of starch into sugar under water stress conditions, contributing as osmolytes in plants under water restrictions. In tomato, an accumulation of soluble solids, soluble sugars, glucose, fructose, and vitamin C was observed when plants were irrigated with saltwater (LI et al., 2019). Furthermore, according to Pereira et al. (2017), the higher TSS content in fruits from plants irrigated with high-salinity water is probably due to the reduction in the average mass of the fruits caused by the deleterious effects of salts, as explained previously, which can increase the concentration of photoassimilates (solutes).

In the present study, the ATT increased as a function of increasing salinity on the order of 9.87% per unit increase in ECa. The lowest value was related to irrigation with supply water (ECa = 0.3 dS m $^{-1}$), which presented an average of 0.082 g citric acid 100 g $^{-1}$, and the highest value was 0.114 g citric acid 100 g $^{-1}$ when the irrigation depth was 4.5 dS m $^{-1}$ (Figure 3).

Figure 3. Total titratable acidity as a function of electrical conductivity of irrigation water for 'Florida Market' eggplant grown in a protected environment under continuous drip and pulse irrigation.

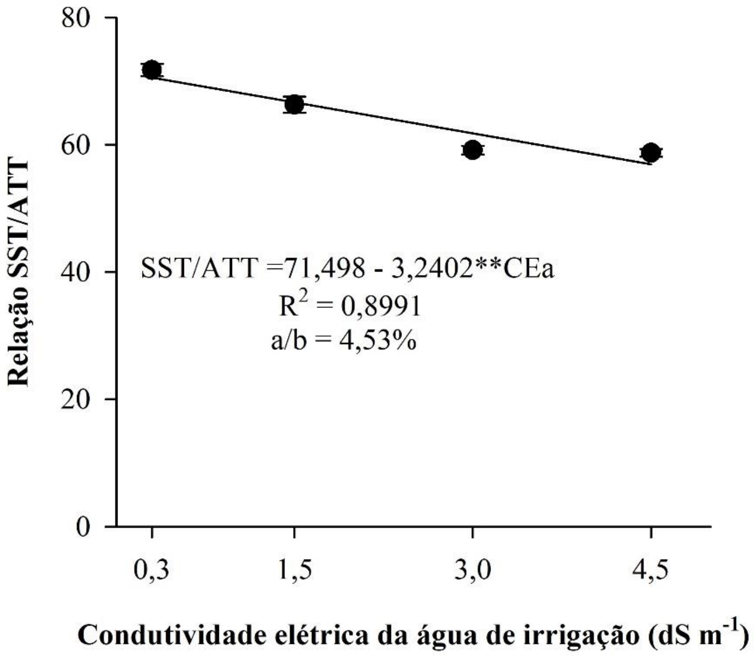


** - significant at p < 0.01; vertical bars represent standard deviations (n=5)
Source: Irriga (2021)

For tomato crops, Li et al. (2019) also reported relatively high concentrations of titratable acidity when irrigated with saline water (3.0 dS m $^{-1}$) mixed with low-salinity water or irrigated with saltwater only at tolerant stages (after the fruiting stage). However, the results differed from those reported by Oliveira et al. (2016) and Oliveira et al. (2019) for eggplant, who reported values of 0.12 and 2.18 g citric acid 100 g $^{-1}$, respectively. According to these authors, eggplant is part of a group of vegetables (fruits) classified as having low acidity (with a pH greater than or equal to 4.5); such divergences in behavior may have been influenced by the response of the cultivar used. Furthermore, according to Oliveira et al. (2016), metabolic changes in eggplant may be associated with environmental cultivation conditions.

The highest ATT values directly reflected the SST/ATT ratio; for the highest CEa levels, a lower ratio was observed (Figure 4). In most fruits, titratable acidity represents one of the main components of flavor, as its acceptance depends on the balance between acids and sugars, with the loss of acidity being considered desirable for most fruits. ATT is also important for the ripening process, where it is probably converted to sugars (CHITARRA; CHITARRA, 2005).

Figure 4. Ratio of total soluble solids and total titratable acidity (TSS/TTA) as a function of the electrical conductivity of irrigation water in the fruits of 'Florida Market' eggplants grown in a protected environment under continuous drip and pulse irrigation.



** - significant at $p < 0.01$; vertical bars represent standard deviations (n=5)
Source: Irriga (2021)

The SST/ATT ratio decreased as a function of increasing water salinity, with a decrease of 4.5% per unit increase (Figure 4). A comparison of the control and maximum salinity treatments revealed that for an ECa of 0.3 dS m $^{-1}$ (supply water), the SST/ATT ratio was 70.52, and for an ECa of 4.5 dS m $^{-1,}$ it was 56.91.

Even with the reduction due to the increase in salinity, the lowest values were higher than those obtained by Oliveira et al. (2019), who evaluated the influence of phosphate and potassium fertilization on the physicochemical characteristics of eggplant and reported a TSS/TTA ratio of 47.26. Paiva et al. (2018) reported a TSS/TTA ratio equal to 21.36 for tomato crops irrigated with water with a salinity level of 2.5 dS m $^{-1}$. The authors also reported that high ratios indicate a mild flavor, whereas low values are correlated with an acidic flavor.

The TSS/TTA ratio is one of the most widely used methods for flavor evaluation and is more representative than the isolated measurement of sugars or acidity. When this ratio is high, fruits have a better balance between sugar and acid levels, resulting in a more pleasant flavor (CHITARRA; CHITARRA, 2005). According to Santos (2018), the higher the TSS/TTA ratio in eggplant is, theoretically, the tastier the fruit will be. Therefore, in the present study, the fruits presented a more specific, mild, and balanced flavor in terms of sugar and acid contents.

6 CONCLUSION

Continuous drip and pulse irrigation do not affect the physicochemical characteristics of eggplant, so the recommendation for pulse irrigation should be considered in light of the other benefits the technique can provide. Increasing the salinity of irrigation water increases the total soluble solids and total titratable acidity and decreases the total soluble solids/total titratable acidity ratio, as well as the fresh weight of the fruit. Water salinity and water application methods did not affect the pH of the fruit pulp.

7 ACKNOWLEDGMENTS

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