Physiology and production of cherry tomato cultivars in a hydroponic system using brackish water[1]

Fisiologia e produção de cultivares de tomate cereja em sistema hidropônico utilizando água salobra

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HIGHLIGHTS:
The physiology and production of cherry tomatoes are negatively affected by use of brackish water.
Saline solution with electrical conductivity of 8.5 dS m^{-1} is highly injurious to the development of cherry tomatoes.
Characterization of cherry tomatoes cultivars with adaptability to salt stress for use in breeding.

ABSTRACT: Agricultural production has become a challenge in arid and semi-arid regions due to the scarcity of water for irrigation, so brackish water is commonly used. The present study aimed to evaluate the physiological and production responses of cherry tomato cultivars under salinity levels of the nutrient solution in a hydroponic system. The experiment was conducted in a split plot and 5 × 3 factorial scheme with four repetitions. The factors corresponded to different values of electrical conductivity of the nutrient solution (ECns 2.5, 4.0, 5.5, 7.0 and 8.5 dS m^{-1}) and cultivars (Samambaia, Tomate Vermelho and Caroline). The increase in nutrient solution salinity negatively affected the gas exchange, electrolyte leakage and photosynthetic pigments of the cherry tomato cultivars, mainly with the prolongation of stress. The photosynthetic system was efficient up to 4.0 dS m^{-1}, but, above this electrical conductivity in the nutrient solution, there was photoinhibition or photodamage in the cherry tomato plants at 30 days after transplanting. The cherry tomato cultivars Samambaia and Caroline were the most adapted to brackish solutions, while Tomate Vermelho was the most susceptible.

Key words: salinity tolerance, soilless cultivation, gas exchange, chlorophyll

RESUMO: A produção agrícola tem se tornado um desafio nas regiões áridas e semiáridas devido à escassez de água para irrigação, sendo comum o uso de água salobra. Objetivou-se avaliar as respostas fisiológicas e produtivas de cultivares de tomate cereja sob diferentes salinidades da solução nutritiva em sistema hidropônico. O experimento foi conduzido em parcela subdividida e esquema fatorial 5 × 3, com quatro repetições. Os fatores corresponderam a valores da condutividade elétrica da solução nutritiva (CEsn 2,5, 4,0, 5,5, 7,0 e 8,5 dS m^{-1}) e cultivares (Samambaia, Tomate Vermelho e Caroline). O aumento da salinidade da solução nutritiva afetou negativamente as trocas gasosas, o extravasamento de eletrólitos e os pigmentos fotossintetizantes das cultivares de tomate cereja, principalmente com o prolongamento do estresse. O sistema fotossintético foi eficiente até 4,0 dS m^{-1}, mas, a partir desta condutividade elétrica na solução nutritiva houve fotoinibição ou fotodanos nas plantas de tomate cereja, com 30 dias após o transplantio. As cultivares de tomateiro cereja Samambaia e Caroline foram as mais adaptadas às soluções salobras, enquanto a cultivar Tomate Vermelho mais suscetível.

Palavras-chave: tolerância à salinidade, cultivo sem solo, trocas gasosas, clorofila

INTRODUCTION

Currently, Brazil occupies the 9th place globally in tomato production, with 3.91 million tons per year and, among the Brazilian states, Paraíba occupies the 13th place with a production of 13.7 thousand tons (IBGE, 2017). Among the main tomato groups, cherry tomato is the one with the lowest domestic production. However, it has gained prominence due to its properties, such as high antioxidant activity, soluble solids content and vitamin C (Guedes et al., 2015).

In Brazil, the quality of water used in irrigation has been one of the most limiting factors for tomato production, especially in the semi-arid region, where most springs have high salt concentrations. In this region, water salinity is highly variable and can reach electrical conductivity, for example, of 4.78 dS m^{-1} (Medeiros et al., 2017), which causes serious damage to the crop, which is considered moderately sensitive to water salinity, with a threshold of 2.5 dS m^{-1} (Ayers & Westcot, 1999). However, this threshold value also depends on the cultivar and on the management strategies used (Silva et al., 2018).

Hydroponic cultivation has expanded significantly compared to conventional cultivation, as it promotes higher yield and quality of production, reductions in the occurrence of diseases and waste of water and nutrients, and optimization in the use of the production area (Gomes et al., 2011; Silva et al., 2018). In addition, in the hydroponic system, due to the absence of soil, there is no influence of the matric potential, consequently the plant has greater tolerance to high salinity in the nutrient solution.

In tomato crop, several studies have demonstrated the beneficial effects of the hydroponic system on increasing the production and efficiency in the use of water and fertilizers (Rosa-Rodríguez et al., 2020), but studies that address salinity in hydroponics with this crop are limited (Pailles et al., 2020). Physiological aspects are determining factors to analyze salinity interference in crop yield, as they are the first ones to be hampered and can reduce yield by about 50% (Cruz et al., 2017).

Therefore, knowing that there is variability in tomato tolerance to salinity among cultivars of the same species (Murillo-Amador et al., 2017), the objective was to evaluate physiological and production characteristics of different cherry tomato cultivars in hydroponic system using brackish water in the preparation of the nutrient solution.

MATERIAL AND METHODS

The experiment was carried out from March to May 2018 at Riachão Farm, located in the municipality of Boa Vista, Paraíba, Brazil (7° 16' 27.36" S, 36° 17' 59.29" W and average altitude of 475 m). The mean temperature during experimental period was 23.5 °C, with air relative humidity of 86%.

The study was conducted in an area of 100 m^2, in the open field, where the entire structure of the hydroponic system was installed. The experimental design was a split plot and 5 x 3 factorial scheme, corresponding to five electrical conductivity of the nutrient solution - ECns (2.5, 4.0, 5.5, 7.0 and 8.5 dS m^{-1}) and three cultivars of cherry tomato (Samambaia, Tomate

Vermelho, and Caroline), with 4 repetitions and two usable plants per plot.

The NFT hydroponic system used was adapted in 6-m-long channels made of 0.075-m-diameter PVC tubes at 2% slope, containing circular holes with 0.06 m in diameter, spaced by 0.5 m. Benches with sawhorses made of 0.05-m-diameter wood were used to support the hydroponic channels at 0.60 m height from the soil; three hydroponic channels were used per bench, with a horizontal spacing of 0.50 m. In addition, a 1.5-m-wide corridor was left between the benches to facilitate traffic and operability. Each plot was represented by an independent hydroponic channel, composed of a 500-L plastic tank containing the nutrient solution and a 32-W electric pump to recirculate the solution, with flow rate of 8 L min^{-1}. The electric pumps were connected to an analog timer programmed to be activated for 15 min at 0.25-hour intervals during the day and 0.5-hour intervals at night (Bliska & Honório, 1996).

Seeds of the three cherry tomato cultivars were placed to germinate in phenolic foam and, five days after emergence, the seedlings were transferred to nursery, where they spent 15 days receiving solution at 50% of the nutritional concentration (Fernandes et al., 2002), with the following composition for macronutrients: N = 8 mmol L^{-1}, P = 2 mmol L^{-1}, K = 4 mmol L^{-1}, Ca = 2 mmol L^{-1}, Mg = 1 mmol L^{-1}, S = 1 mmol L^{-1}. For micronutrients, a commercial product was used, ConMicros-Allplant, with the following composition: Fe = 35 µmol L^{-1}, Zn = 2 µmol L^{-1}, Cu = 4 µmol L^{-1}, Mn = 5 µmol L^{-1}, B = 22 µmol L^{-1}, Mo = 1 µmol L^{-1}, Ni = 1 µmol L^{-1}. The fertilizers used as a source of macronutrients were: urea (45% N), magnesium sulfate (9% Mg and 11% S), calcium nitrate (18.5% Ca and 15.5% N), potassium chloride (60% K$_2$O) and purified MAP (61% P$_2$O$_5$ and 12% N), all fertilizers were weighed on a high-precision digital scale.

Then, plants were transplanted to the definitive profiles, where they spent 10 days of acclimation before the saline treatments began to be applied, receiving 100% solution (Fernandes et al., 2002). The water used to prepare the nutrient solution came from an artesian well with ECw = 1.8 dS m^{-1} and, after addition of nutrients, showed ECns = 2.5 dS m^{-1}, characterizing the lowest level of salinity. To obtain the other levels of nutrient solution salinity, after the dissolution of nutrients, the salts sodium chloride (NaCl), calcium chloride (CaCl$_2$.2H$_2$O) and magnesium chloride (MgCl$_2$.6H$_2$O) were dissolved in the equivalent proportion of 7:2:1, according to Richards (1954), resulting in electrical conductivity values of 4.0, 5.5, 7.0 and 8.5 dS m^{-1}. The equivalent proportion of 7:2:1 was used because these are the main salts found in the saline waters in semi-arid regions and, based on an overall average, are present approximately in this proportion.

The solutions were monitored daily to ensure the correct electrical conductivity of each treatment, with a portable conductivity meter, and a 30% variation range was estimated for each salinity level, as it is very difficult to maintain the exact ECw of each treatment, since the experiment was carried out in the field, with great variation in climatic conditions during the day, which causes oscillations in the plant in terms of absorption of nutrients from the nutrient solution, also avoiding the imbalance of the solutions. All solutions

were renewed weekly, together with the control of electrical conductivity. The pH was monitored using a portable digital pH meter, and the most frequent variations were associated with the increase of pH, corrected to a range of 5.5 – 6.5 with the addition of 20% sulfuric acid.

At 15 and 30 days after application of saline treatments (DAT), evaluations of gas exchange, relative water content, electrolyte leakage and photosynthesizing pigments were performed. At 30 DAT, the plants with the highest salinity level in the nutrient solution (8.5 dS m⁻¹) showed advanced symptoms of salinity-induced stress in the leaves, such as necrosis at the edges, wilt and chlorosis, so it becames impossible to perform physiological evaluations in this treatment.

Gas exchange was evaluated, between 8:30 and 11:00 a.m., with a portable infrared carbon dioxide analyzer (LCPro+ from ADC BioScientific Ltda), on the third leaf from the apex under saturating irradiance (1000 μmol m^{-2} s^{-1}). The variables analyzed were photosynthesis (A), stomatal conductance (gs) and transpiration (E).

Relative water content (RWC) was obtained from five discs ($\emptyset$ = 0.771 mm) extracted from the third leaf. The discs were initially weighed (FW), then put to saturate in distilled water for 24 hours, and weighed again (TW). Subsequently, the discs were placed in an oven at 65 ºC and kept for 24 hours, thus obtaining the dry weight (DW). RWC was calculated according to Cairo (1995), as shown in Eq. 1:

$$RWC = \frac{FW - DW}{TW - DW} 100 \qquad (1)$$

where:

FW, TW and DW - represent the fresh weight, turgid weight and dry weight of the discs (g), respectively.

Electrolyte leakage (EL) was also determined using five leaf discs ($\emptyset$ = 0.771 mm), which were washed in distilled water to remove other electrolytes adhered to the leaves and then placed in beakers containing 50 mL of distilled water. The beakers were left at room temperature for 1.5 hours, to measure the initial electrical conductivity (Ci). Subsequently, the beakers were heated to 80 ºC for 1.5 hours, when the final electrical conductivity (Cf) was measured. Thus, EL was obtained according to Scott-Campos (1997), as shown in Eq. 2:

$$EL = \frac{Ci}{Cf} 100 \qquad (2)$$

The photosynthesizing pigments were quantified by extracting two leaf discs ($\emptyset$ = 0.771 mm), which were crushed, placed in containers with 6 mL of 80% acetone and kept in the dark for 72 hours; then, the supernatant was collected, and spectrophotometer readings were taken at absorbances of 470, 647 and 663 nm. After that, chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll and carotenoid contents were quantified according to the protocol of Arnon (1949).

At the end of the experiment, at 30 DAT, all fruits of each plant were quantified and weighed to obtain the total weight (g plant⁻¹), because the first two bunches of all plants were already

in an appropriate maturity degree for harvest and marketing. However, in this period it was not possible to harvest all the fruits of the plant at the final stage of maturity; despite that, all fruits per plant were weighed and the total weight up to that time was evaluated.

The obtained data were subjected to analysis of variance by the F test, at $p \leq 0.05$ and $p \leq 0.01$. In the case of significance, of the interaction between the factors or of the main factors alone, linear and quadratic regression was performed for the ECns factor and Tukey test for the cultivars factor, using the software for statistical analysis Sisvar (Ferreira, 2014).
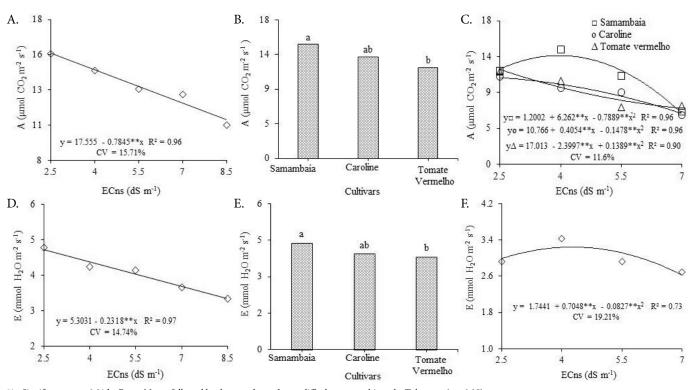
Results and Discussion

The net CO$_2$ assimilation (A) of cherry tomato at 15 DAT decreased linearly with increasing salinity of the nutrient solution, regardless of the cultivar used, with reductions of 4.5% per unit increase in ECns, resulting in a reduction of 32% between the lowest (2.5 dS m⁻¹) and the highest (8.5 dS m⁻¹) electrical conductivity (Figure 1A). This result can be explained by the fact that excess of salts in the water reduces the osmotic potential in the roots, causing leaf stomatal closure in response to stress, consequently leading to decreases in CO$_2$ assimilation, transpiration and stomatal conductance (Taiz et al., 2017). Similar reductions in gas exchange were also observed by Tatagiba et al. (2014) with the tomato cv. Santa Clara.

Among the cultivars, individually, the cv. Samambaia differed statistically from Tomate Vermelho, with A of 15 μmol m⁻² s⁻¹ CO$_2$ (Figure 1B). At 30 DAT, all cultivars were affected by the increase in electrical conductiivity of the nutrient solution (Figure 1C), when the cv. Samambaia showed quadratic behavior, obtaining a maximum value of A (13.62 μmol m⁻² s⁻¹ CO$_2$) at ECns of 3.9 dS m⁻¹, while the cultivars Caroline and Tomate Vermelho showed linear reductions of about 56 and 63%, respectively, between the lowest ECns (2.5 dS m⁻¹) and the highest ECns (7.0 dS m⁻¹). Gomes et al. (2011), evaluating the cv. Samambaia in hydroponic system using coconut fiber substrate, also observed tolerance of this cultivar to the salinized nutrient solution, obtaining salinity threshold around 3.51 dS m⁻¹.

This behavior of the cultivars at 30 DAT can be explained by genetic diversity. In the study conducted by Murillo-Amador et al. (2017) on the physiology of eight tomato cultivars (Tropic, Feroz, Ace, Super Rio Grande, Yaqui, Missouri, Vita and Floradade) with salinized nutrient solutions, the authors observed that the most salt-tolerant cultivar was Missouri, followed by Ace, Yaqui, Tropic, Floradade, Feroz, Vita and Super Rio Grande, and reported that physiological characteristics can be used as an effective means for screening for salinity tolerance in tomato cultivars.

The transpiration rate of cherry tomato plants (E), at 15 DAT, also decreased with the increase in the electrical conductivity of the nutrient solution of the nutrient solution (Figure 1D), with a reduction of 4.4% per unit increase in ECns, resulting in a 30% decrease between the lowest ECns (2.5 dS m⁻¹) and the highest ECns (8.5 dS m⁻¹). Among the tomato cultivars, as observed for A, the cv. Samambaia had higher transpiration compared to Tomate Vermelho, which showed

Figure 1. Photosynthesis - A (A and C) and transpiration - E (D and F) at 15 and 30 days after application of saline treatments (DAT), as a function of the electrical conductivity of the nutrient solution - ECns. Photosynthesis (B) and transpiration (E) for different cherry tomato cultivars at 15 DAT

lower E. Probably, the genetic difference between these cultivars leads to distinct responses, regardless of the environmental conditions to which they are exposed (Figure 1E).

At 30 DAT, E varied only between electrical conductivity of the nutrient solution, and the maximum transpiration (3.25 mmol m^{-2} s^{-1}) was reached at ECns of 4.3 dS m^{-1}, decreasing from this value on (Figure 1F). As a defense mechanism, the plant reduces its transpiration rate when there are excess of salts in the solution, in order to retain a greater amount of water in the leaf, besides reducing the absorption and transport of Na$^+$ and Cl$^-$ ions to its tissues, thus mitigating the deleterious effects of salinity (Ebrahim et al., 2017). Similar results were observed by Cavalcante et al. (2019) when studying gas exchange in bell pepper plants subjected to increasing electrical conductivity of the nutrient solution in hydroponic system, which reduced E on average by 67% between the lowest and highest ECns.
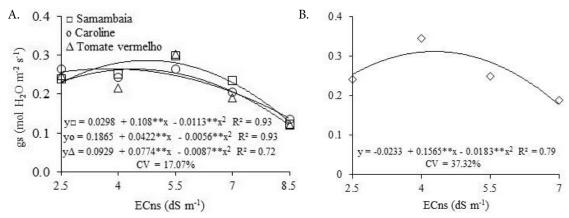
The excess of ions in the brackish solution significantly reduced stomatal conductance (gs) in all cultivars at 15 DAT (Figure 2A), and the cultivars Samambaia, Tomate Vermelho and Caroline showed a decrease in gs from ECns values of 4.8, 4.5 and 2.4 dS m^{-1}, respectively, reaching maximum gs of 0.288, 0.265 and 0.255 mol m^{-2} s^{-1}, which hence demonstrates that the cv. Samambaia obtained higher gs with higher ECns (4.8 dS m^{-1}), thus being the most adapted to ECns. At 30 DAT, variation was observed only between electrical conductivity of the nutrient solution for all cultivars, in which the increase in salinity of the nutrient solution affected gs, which reached a maximum of 0.311 mol m^{-2} s^{-1} of H$_2$O at ECns of 4.2 dS m^{-1}, decreasing from this value on (Figure 2B).

The lower gs obtained by plants under salt stress is probably related to the fact that, even under hydroponic conditions, salinity

reduces the absorption of water in the roots through its osmotic effect and, subsequently, induces water stress (Taiz et al., 2017).

The relative water content (RWC), at 15 DAT, varied among the cultivars with the increase of salinity in the nutrient solution, and the cvs. Samambaia, Tomate Vermelho and Caroline had maximum estimated RWC of 67.35, 68.41 and 65.88 with ECns of 5.8, 5.4 and 4.0 dS m^{-1}, respectively (Figure 3A), thus indicating that the cv. Caroline was the most sensitive to the salinity of the nutrient solution, since low RWC points to greater dehydration of tissues under stress conditions and, consequently, lower plant growth (Sousa et al., 2017).
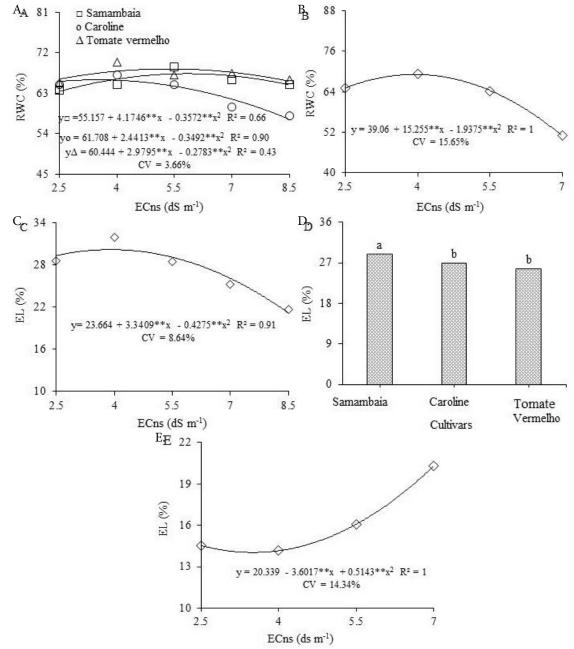
At 30 DAT, the RWC decreased, regardless of the cultivar, as the electrical conductivity of the nutrient solution increased, and from the value of 4.0 dS m^{-1}, there was a 14% reduction between the lowest salinity (2.5 dS m^{-1}) and the highest one (7.0 dS m^{-1}) (Figure 3B). Although the cultivars Samambaia and Tomate Vermelho had higher RWC at 15 DAT, with the prolongation of stress all cultivars reduced their RWC, indicating that the plants lost cell turgor with the severity of stress, which affected their development, since plant growth depends on cell turgor. However, the higher RWC in the cvs. Samambaia and Tomate Vermelho, at 15 DAT, points to physiological acclimation to salt stress, which ultimately affects the growth and production of these cultivars.

The increase in the electrical conductivity of the nutrient solution caused a reduction in electrolyte leakage when the plants were cultivated with nutrient solution from 4.0 dS m^{-1} at 15 DAT (Figure 3C). This result differs from those found in most of the literature, where generally, with the presence of salt stress, the plant shows greater cell damage. However, this may have occurred due to the time of exposure of plants to the stress

A.

$y_\square = 0.0298 + 0.108^{**}x - 0.0113^{**}x^2 \quad R^2 = 0.93$
$y_o = 0.1865 + 0.0422^{**}x - 0.0056^{**}x^2 \quad R^2 = 0.93$
$y_\triangle = 0.0929 + 0.0774^{**}x - 0.0087^{**}x^2 \quad R^2 = 0.72$
CV = 17.07%

B.

$y = -0.0233 + 0.1565^{**}x - 0.0183^{**}x^2 \quad R^2 = 0.79$
CV = 37.32%

** - Significant at $p \leq 0.01$ by F test

Figure 2. Stomatal conductance – gs of tomato at 15 days after application of saline treatments (DAT), for different cultivars as a function of the electrical conductivity of the nutrient solution - ECns (A) and at 30 DAT as a function of only the ECns (B)
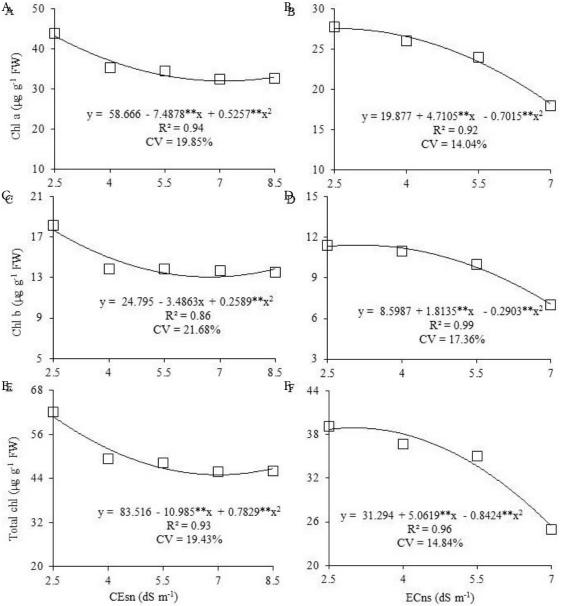

A.

$y_\square = 55.157 + 4.1746^{**}x - 0.3572^{**}x^2 \quad R^2 = 0.66$
$y_o = 61.708 + 2.4413^{**}x - 0.3492^{**}x^2 \quad R^2 = 0.90$
$y_\triangle = 60.444 + 2.9795^{**}x - 0.2783^{**}x^2 \quad R^2 = 0.43$
CV = 3.66%

B.

$y = 39.06 + 15.255^{**}x - 1.9375^{**}x^2 \quad R^2 = 1$
CV = 15.65%

C.

$y = 23.664 + 3.3409^{**}x - 0.4275^{**}x^2 \quad R^2 = 0.91$
CV = 8.64%

D.

E.

$y = 20.339 - 3.6017^{**}x + 0.5143^{**}x^2 \quad R^2 = 1$
CV = 14.34%

** - Significant at $p \leq 0.01$ by F test

Figure 3. Relative water content - RWC in tomato cultivars as a function of the electrical conductivity of the nutrient solution - ECns at 15 days after application of saline treatments - DAT (A), RWC at 30 DAT as a function of ECns (B), electrolyte leakage – EL as a function of ECns (C) and of tomato cultivars at 15 DAT (D), and EL as a function of ECns at 30 DAT (E)

(15 days), so their tolerance strategies were still effective, such as increased cell wall thickness and membrane strengthening (Lima et al., 2011). In the same period, an individual effect was found between the cultivars, in which the cv. Samambaia had higher electrolyte leakage compared to the cultivars Caroline and Tomate Vermelho (Figure 3D).

On the other hand, at 30 DAT, with the exposure of plants to salt stress, there was an increase in the percentage of electrolytes leaked with the increase in ECns, with the lowest EL (14.03%) at the estimated ECns of 3.5 dS m^{-1}, increasing from this value on (Figure 3E). Such increase is associated with the effect of phytotoxicity of salts on plant organs, due to the accumulation of ions in the tissues, which causes changes in the composition of membrane structures and cellular organelles, resulting in morphophysiological changes in the plants, such as chlorophyll degradation (Munns, 2005; Silva et al., 2008). Similar results were observed in castor bean (Ferraz et al., 2015) and citrus (Sousa et al., 2017) plants, with greater release of electrolytes as the electrical conductivity increased.

The increase of salinity in the nutrient solution at 15 DAT resulted in a decrease in chlorophyll a content, and the lowest Chl a content (32.0 µg g^{-1} FW) was obtained at the estimated ECns of 7.12 dS m^{-1} (Figure 4A). At 30 DAT, Chl a reached its maximum (27.78 µg g^{-1} FW) at the estimated ECns of 3.35 dS m^{-1}, with reduction from this value up to 7.0 dS m^{-1} (Figure 4B), indicating that, at 30 DAT, the salinity of the nutrient solution drastically affected chlorophyll biosynthesis in tomato plants. Similar results were found in tomato plants under salinity, which showed a decrease in chlorophyll a content (Moles et al., 2016).

Mendonça et al. (2010) state that plants that grow under salinity conditions show reduction in their photosynthetic activity, which results in reduced growth, with smaller leaf area and lower chlorophyll content. According to Fiaz et al. (2014), salt stress causes a reduction in the enzymatic activity of protochlorophyllide reductase, inhibiting the conversion of the respective precursors into photosynthetic pigments (chlorophyll), so this reduction is the main reason

$$y = 58.666 - 7.4878^{**}x + 0.5257^{**}x^2$$
$$R^2 = 0.94$$
$$CV = 19.85\%$$

$$y = 19.877 + 4.7105^{**}x - 0.7015^{**}x^2$$
$$R^2 = 0.92$$
$$CV = 14.04\%$$

$$y = 24.795 - 3.4863x + 0.2589^{**}x^2$$
$$R^2 = 0.86$$
$$CV = 21.68\%$$

$$y = 8.5987 + 1.8135^{**}x - 0.2903^{**}x^2$$
$$R^2 = 0.99$$
$$CV = 17.36\%$$

$$y = 83.516 - 10.985^{**}x + 0.7829^{**}x^2$$
$$R^2 = 0.93$$
$$CV = 19.43\%$$

$$y = 31.294 + 5.0619^{**}x - 0.8424^{**}x^2$$
$$R^2 = 0.96$$
$$CV = 14.84\%$$

** - Significant at p ≤ 0.01 by F test

Figure 4. Concentrations of chlorophyll a (A and B), chlorophyll b (C and D) and total chlorophyll (E and F) at 15 and 30 DAT, respectively, of cherry tomatoes as a function of the electrical conductivity of the nutrient solution - ECns

for the lower production of photosynthetic pigments, consequently influencing the photosynthetic rate, production of photoassimilates and fruit production.

Chlorophyll b showed a behavior similar to that of Chl a, with a reduction of 24% at 15 DAT and, when comparing plants cultivated with nutrient solution from 2.5 to 4 dS m^{-1}, from this value the reduction was 7% up to the highest salinity of the solution (8.5 dS m^{-1}) (Figure 4C). At 30 DAT, there was no reduction of Chl b up to the electrical conductivity of the nutrient solution of 4 dS m^{-1}, while from this value up to 7 dS m^{-1}, there was a reduction of 36% (Figure 4D). Reduction of chlorophyll b in tomato plants under salt stress has also been found by other authors (Tatagiba et al., 2014; Ebrahim et al., 2017). These results can be explained by taking into account that the water deficit caused by salt stress benefits the synthesis of reactive oxygen species, which hamper plant metabolism, among other reasons, for inducing oxidation of photosynthetic pigments, including chlorophyll b (Silva et al., 2016).
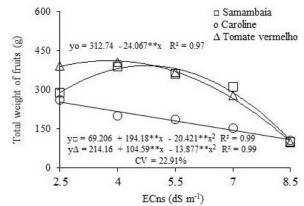
At 15 DAT, the total chlorophyll concentration of tomato plants decreased by 21% and, in a comparison of the nutrient solutions with 2.5 and 4 dS m^{-1}, from this value on the reduction was equal to 6% up to the highest salinity of the solution (8.5 dS m^{-1}) (Figure 4E). At 30 DAT, total chlorophyll reduced by 5% up to the electrical conductivity of the nutrient solution of 4 dS m^{-1}, while from this value up to 7 dS m^{-1}, the reduction was 32% (Figure 4F).

Indeed, in plants subjected to high levels of ions in the solution there are structural changes in photosynthetic pigments, thus compromising the efficiency of excitation energy from the light-harvesting antenna, and damage to photosystem II reaction centers (Tatagiba et al., 2014), which also affects photosynthesis, as observed in this study.

The carotenoid concentration of tomato plants decreased with increasing salinity in the nutrient solution, in both evaluation periods. At 15 DAT, the lowest carotenoid concentration (4.6 μg g^{-1} FW) was obtained at the estimated ECns of 8.3 dS m^{-1} (Figure 5A). At 30 DAT, the carotenoid concentration decreased by 23.7% between the lowest (2.5 dS m^{-1}) and the highest (7.0 dS m^{-1}) electrical conductivity of the nutrient solution (Figure 5B). Carotenoids are accessory pigments that dissipate the excess of light energy used by the
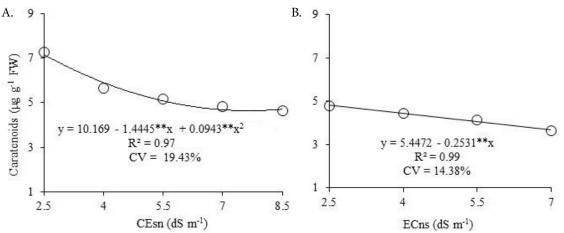
plant species, especially under conditions of abiotic stresses such as salinity, in which they play a photoprotective role (Silva et al., 2016). Thus, it is suggested that carotenoids performed photoprotection in tomato plants with the prolongation of salt stress, since the reduction of these pigments was higher at 15 than at 30 DAT.

The production of fruits per plant of the tomato cultivars decreased with increasing electrical conductivity of the nutrient solution (Figure 6). The cultivars Samambaia and Tomate Vermelho reached the estimated maximum total weights of 392.40 and 411.23 g, at salinity levels of 4.75 and 3.76 dS m^{-1}, respectively. Conversely, for the cultivar Caroline, production decreased linearly as the electrical conductivity of the nutrient solution increased, with a reduction of 24 g per unit increase in ECns, representing a decrease of 62% between the lowest (2.5 dS m^{-1}) and the highest (8.5 dS m^{-1}) electrical conductivity of the nutrient solution (Figure 6). Similar results were reported by Guedes et al. (2015), who evaluated the cherry tomato cv. Caroline and observed a reduction of 62% in production when plants were irrigated with saline water of 3.5 dS m^{-1}, whereas Gomes et al. (2011) also working with cherry tomatoes, cv. Samambaia, in hydroponic cultivation under salinity, observed a reduction in the production of approximately 34% between the electrical conductivity of 2.1 and 7.0 dS m^{-1}. This reduction

** - Significant at p ≤ 0.01 by F test

Figure 6. Total weight of fruits per plant at 30 days after application of saline treatments as a function of the electrical conductivity of the nutrient solution - ECns
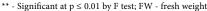
** - Significant at p ≤ 0.01 by F test; FW - fresh weight

Figure 5. Carotenoid concentrations at 15 (A) and 30 (B) days after application of saline treatments of cherry tomatoes as a function of the electrical conductivity of the nutrient solution - ECns

in production with the increase in electrical conductivity of the nutrient solution is the response of tomato plants to the damage caused by the increase of salt stress in the plant, affecting from growth to physiological processes such as photosynthesis, relative water content and integrity of membranes (Tatagiba et al., 2014; Sousa et al., 2017).

Conclusions

1. Increase in nutrient solution salinity negatively affected the gas exchange, electrolyte leakage and photosynthesizing pigments of cherry tomato cultivars, especially with prolongation of the stress.

2. The photosynthetic system was efficient up to 4.0 dS m^{-1}, but, from this conductivity in the nutrient solution there was photoinhibition or photodamage in cherry tomato plants, at 30 DAT.

3. The cherry tomato cultivars Samambaia and Caroline were the most adapted to the solutions, while the cultivar Tomate Vermelho was the most susceptible.

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