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Production and quality of bell pepper fruits grown under saline stress in different substrates

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ABSTRACT

The aim of this study was to evaluate the salinity effect on the production and quality of bell pepper fruits (*Capsicum annuum* L.) grown in different substrates. The experimental design adopted was randomized blocks, in a 3 × 4 factorial scheme, with three substrates {coconut fiber, sand and mixture [coconut fiber + sand (1:1)]}, and four salinity levels of the nutrient solution (2.2; 3.5; 4.5 and 5.5 dS/m), with three replicates. The first fruit harvest was 60 days after transplanting (DAT) and the others weekly. The following variables were evaluated: number of fruits (marketable, unmarketable and total), average mass of marketable fruits, fruit production (marketable and total), soluble solid content, titratable acidity, soluble solids/titratable acidity ratio, vitamin C and fruit firmness. The largest fruit production occurred with coconut fiber (947.27 g/plant) and mixture (763.71 g/plant). The type of substrate has little influence on the quality of bell pepper fruits produced under salinity stress up to 4.5 dS/m. Coconut fiber and mixture are the most recommended substrates for bell pepper production under salinity stress up to 3.5 dS/m.

Keywords: *Capsicum annuum* L., salinity, coconut fiber, yield, soluble solids.

RESUMO

Produção e qualidade de frutos de pimentão cultivados sob estresse salino em diferentes substratos

O objetivo deste trabalho foi avaliar o efeito da salinidade na produção e qualidade de frutos de pimentão (*Capsicum annuum* L.) cultivado em diferentes substratos. O delineamento adotado foi de blocos casualizados, em esquema fatorial 3 × 4, sendo três substratos {Fibra de coco, Areia e Mistura [Fibra de coco+Areia (1:1)]} e quatro salinidades da solução nutritiva (2,2; 3,5; 4,5 e 5,5 dS/m), com três repetições. A primeira colheita de frutos foi aos 60 dias após o transplantio (DAT) e as demais semanalmente. Foram avaliadas as seguintes variáveis: número de frutos (comerciais, não comerciais e total), massa média de frutos comerciais, produção de frutos (comercial e total), teor de sólidos solúveis, acidez titulável, razão sólidos solúveis/acidez titulável, vitamina C e firmeza dos frutos. A maior produção de frutos ocorreu com os substratos Fibra de coco (947,27 g/planta) e Mistura (763,71 g/planta).O tipo de substrato exerce pouca influência sobre a qualidade dos frutos de pimentão produzidos sob estresse salino até 4,5 dS/m. Os substratos Fibra de coco e Mistura são os mais recomendados para a produção de pimentão em condições de estresse salino até 3,5 dS/m.

Palavras-chave: *Capsicum annuum* L., salinidade, fibra de coco, rendimento, sólidos solúveis.

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Bell pepper (*Capsicum annuum* L.) is one of the most economically important vegetables grown in tropical and subtropical countries worldwide (Tiamiyu *et al*., 2023). Its fruits are an excellent source of substances beneficial for human health, such as flavonoids, vitamins (A and C), phenolic acids and minerals (Kaur *et al*., 2020; Brezeanu *et al*., 2022).

Despite the fact that peppers are predominantly grown in soil in Brazil, some studies on these plants are carried out in a protected environment, mainly under hydroponic system with substrates (also called semi-hydroponic) (Lima *et al*., 2017; Silva *et al*., 2020; Oliveira *et al*., 2022).

In this production system, as well as in soil cultivation, the quality of water used to prepare the nutrient solution is essential, especially when it comes to salt concentration dissolved in it. Salinity causes osmotic stress, ionic imbalance, nutritional deficiency, oxidative stress, as well as a decrease in photosynthesis, resulting in a reduced plant growth and productivity (Arif *et al*., 2020).

Hydroponic cultivation provides higher plant tolerance to salinity, comparing with soil cultivation, due to less influence of matrix potential (Santos *et al*., 2016). Thus, the water potential of the plants under these conditions is affected mainly by the osmotic potential, either due to the use of saline water or the high concentration of fertilizers in the nutrient solution (Soares *et al*., 2016).

Like most vegetables, bell peppers are highly sensitive to saline water. This vegetable is a salt sensitive plant, which shows a significant reduction in fruit production when irrigated with water presenting electrical conductivity above 1.0 dS/m or 1.5 dS/m of soil saturation extract (Ayers & Westcot, 1999).

Some studies have shown that using saline water in the nutrient solution considerably affects morpho-physiological processes, gas exchanges and photosynthetic pigments of the bell pepper plant (Lima *et al*., 2017; Furtado *et al*., 2022), resulting in reduced growth, yield losses and changes in fruit quality (Lima *et al*., 2017; Silva *et al*., 2020).

Choosing a substrate for cultivation under semi-hydroponic conditions is of great importance, since this substrate has to present high water retention capacity as well as to show good aeration and drainage conditions, enabling to reduce the influence of the matrix potential and to increase nutrient availability for plants, mitigating the harmful effects of high salinity levels (Camposeco-Montejo *et al*., 2018; Silva *et al*., 2021).

Coconut fiber stands out among the substrates evaluated in studies on vegetables/fruits (Silva *et al*., 2020; Oliveira *et al*., 2022). This input shows high water buffering capacity, which makes irrigation management more flexible; its proportion of macropores is favorable to plant roots as it drains away the excess water, facilitates aeration and still provides plenty of water (Nascimento *et al*., 2021). However, these authors highlighted that the coconut fiber shows low air-filled porosity, which can be an issue when it comes to the plant species to be grown and irrigation management to be adopted.

Washed sand has also been evaluated as a substrate for producing plants under semi-hydroponic system. In studies on ornamental sunflower (Santos Júnior *et al*., 2014) and mini watermelon (Silva *et al*., 2021), for example, the authors compare the washed sand with other substrates, including coconut fiber; both studies showed superiority of coconut fiber in relation to washed sand. Studies on the mixture of these substrates under salinity conditions are rare, though.

Considering that salinity stress is one of the main limiting factors for bell pepper production and that the substrate chosen for cultivation can reduce these effects, the aim of this study was to evaluate the salinity effect on production and quality of bell pepper fruits grown in different substrates.

MATERIAL AND METHODS

The experiment was carried out from May to September, 2021, in a greenhouse, at Departamento de Ciências Agronômicas e Florestais (DCAF), in Centro de Ciências Agrárias (CCA), at Universidade Federal Rural do Semi-Árido (UFERSA), in Mossoró, Rio Grande do Norte, Brazil (5º12’4”S; 37º19’39”W, 18 m average altitude).

During the experiment, the authors collected climatic data, such as maximum (Tmax), medium (Tmed) and minimum (Tmin) temperatures, as well as maximum (RHmax), medium (RHmed) and minimum (RHmin) relative air humidity, monitored by an automatic meteorological station (Campbell Scientific Inc. model CR1000), installed inside the greenhouse. Temperatures ranged from 27.99 to 38.14ºC for Tmax; 27.28 to 31.96ºC for Tmed; 20.82 to 28.29ºC for Tmim. For UR, ranges from 56.17 to 100% for RHmax, 48.16 to 88.63 for RHmed and 22.89 to 78.96% for RHmin were verified.

The experimental design used was randomized blocks, in a factorial scheme 3 × 4, with three replications. Each experimental unit consisted of four 10 dm^3-capacity pots, containing one plant in each pot, totalizing 144 plants. The treatments consisted of three substrates: coconut fiber, washed sand and mixture [coconut fiber + washed sand (1:1)] with four electrical conductivity levels of nutrient solutions (2.2; 3.5; 4.5 and 5.5 dS/m) applied via fertigation. The nutrient solution with CE 2.2 dS/m was prepared using water from the supply system of the UFERSA Campus. These substrates were chosen according to their different physical characteristics in order to verify the effect of these characteristics on plant response to salinity stress.

The standard nutrient solution used was recommended by Castellane & Araújo (1994). The authors used 650 $Ca(NO_3)_2$; 506 KNO_3; 170 MAP; 300 $MgSO_4$ and 99.2 KCl. in g for 1000 liters. Micronutrients were supplied by two commercial products: one compost [Dripsol Micro Rexene Equilíbrio Micronutrientes Quelatados (magnesium 1.1%; boron 0.85%; copper (Cu-EDTA), 0.5%; iron (Fe-EDTA), 3.4%; manganese (Mn-EDTA), 3.2%; molybdenum 0.05%; zinc 4.2%)], and the other product was an extra source of iron (Iron chelate Q48 Eddha 6%).

The nutrient solutions were prepared using water from the supply system of the UFERSA Campus. The physical-chemical properties determined the following characteristics: pH = 7.57, CE = 0.54 dS/m, Ca^{2+} = 0.83, Mg^{2+} = 1.20, K^+ = 0.31, Na^+ = 3.79, Cl^- = 2.40, HCO_3 = 3.20 and CO_3^{2-}= 0.60 ($mmol_c$/L). In order to obtain the other solutions (CE2, CE3 and CE4), non-iodized sodium chloride (NaCl) was added into the same water used for the standard nutrient solution (CE1), in quantities of 306.4; 916.9 and 1527.4 g/1000 L, respectively, adjusting the salinity levels with the aid of a conductivity meter.

Bell pepper seedlings, cultivar Gladiador F1 (TOPSEED®), were grown in plastic trays using coconut fiber substrate, one seedling per cell.

The transplanting was carried out at 35 days after sowing, late in the evening, putting one plant per pot.

The crop was drip irrigated, using microtubes emitters (spaghetti), 1.5-mm internal diameter, 10 cm-long, mean flow of 18 L/h, coupled to the polyethylene pipe lateral lines (16 mm). Each nutrient solution was irrigated independently. The system consisted of a circulation pump Metalcorte/Eberle, self-ventilated, model EBD250076, driven by a single-phase motor, 210 V voltage, 60 Hz frequency and a reservoir (a 500-L-capacity water tank).

Fertigation was controlled by a digital timer (model TE-2, Decorlux®), programmed for eight daily irrigations, adjusted according to the crop necessity throughout the development cycle (Table 1). In each irrigation event, sufficient volume was applied to provide drainage of 10% of the applied volume.

The water consumption of the plants was not taken into account, however, in all irrigations the substrate moisture was increased to its maximum water retention capacity, based on the visualization of drainage in the pots.

Seven fruit harvests were performed throughout the experiment, when the fruits reached harvest time (opaque green and/or green-to-red), being the first harvest at 60 days after transplanting (DAT) and the others at a seven-day average intervals. In all harvests, the fruits were evaluated according to the standards proposed by CEAGESP (2021), concerning the following variables: number of marketable fruits (NMF): including all non-defective fruits which presented length and diameter >4 cm, no disease symptoms, deformation or physiological problems; number of unmarketable fruits (NUF): all the fruits which were still small (<4 cm) and/or presented defects, sickness symptoms, deformations or physiological problems; total number of fruits (TNF): all the fruits were counted; average marketable fruit mass (AMFM): the marketable fruits were weighed using an analytical precision scale (0.01 g) and the result obtained by dividing the total fruit fresh mass by the quantity of marketable fruits obtained from a plant, expressed in g/fruit; marketable production (MP): obtained considering all the marketable fruits, considering the accumulated in all harvests, expressed in g/plant; and total production (TP): all the fruits (marketable and unmarketable) were weighed using an analytical precision scale (0.01 g), expressed in g/plant.

Table 1. Irrigation time throughout the bell pepper cycle grown under salinity stress in different substrates. Mossoró, UFERSA, 2021.

Days after transplant (DAT)	Average time of each irrigation	Daily irrigation time (min)
1-17	1 min	8
18-25	1 min 12 s	8.5 min
26-29	1 min 15 s	10 min
30-49	1 min 30 s	10.30 min
50-99	2 min	14 min
100-final	1 min 45 s	12.15 min

Fruit quality was evaluated during the last harvest. The authors evaluated fruit firmness (FIRM): all the fruits were evaluated with the aid of an analogical bench penetrometer (McCormick, model FT 327, a tip of 12 mm), being the results expressed in Newton (N); soluble solid content (SS): performed using a digital refractometer (PR-100 Palette, Atago, scale between 0-32%), being the results expressed in °Brix; titratable acidity (TA): 5 mL of pulp juice was removed and 40 mL of distilled water was added. Then, this solution was titrated with sodium hydroxide solution (0.02 N) until reaching a final pH of 8.15; SS/TA ratio and vitamin C (VITC): determined using a 2.5 mL aliquot of bell pepper pulp juice from each sample, added to a 50 mL volumetric flask filled with oxalic acid. Afterwards, 10 mL of this dilution was removed and mixed with 40 mL of distilled water to titrate with Tilman reagent (f=0.0877 mgAA/mLDFI), until the color of the solution changed to pink.

The obtained data were submitted to tests of normality (Shapiro-Wilk) and homogeneity (Bartlett), and then, to the analyses of variance at 0.05 and 0.01 probability. Unfolding analysis was performed, when a significant response related to the interaction between factors was verified. The effect of the substrates was evaluated using Tukey mean comparison test at 0.05. The effect of salinity levels was analyzed using regression, adjusting to polynomial models. The statistical analyses were performed using the statistical software SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

Number of marketable (NMF), unmarketable (NUF) and total number of fruits (TNF) showed significant response for interaction between substrate and salinity ($p<0.01$), as well as marketable production (MP) at 5% probability. For average marketable fruit mass (AMFM), significant response was verified only for salinity ($p<0.05$). Total production (TP) showed significant response for substrate and salinity, both at 1% probability.

The substrates differed among each other for NMF (Figure 1A), NUF (Figure 1B) and TNF (Figure 1C) in all salinity levels, being the lowest values observed in sand substrate for most situations. On the other hand, no significant differences were noticed for coconut fiber and mixture in most of salinity levels used, except for NMF in the lowest salinity (2.2 dS/m), in which coconut fiber was superior in 46.52 and 165.14% in relation to mixture and sand, respectively (Figure 1A).

The increase in electrical conductivity of the nutrient solution resulted in a linear reduction in NMF (Figure 1A) and TNF (Figure 1C), in plants grown in coconut fiber substrate, showing losses of 1.50 and 1.69 fruits/plant, respectively, per unit increase of salinity. Thus, the highest values were observed in the lowest salinity (2.2 dS/m), being 13.92 marketable fruits and 22.21 the total number of fruits/plant. In the highest salinity, we noticed reductions of 31.17 and 21.30%, for NMF and TNF, respectively (Figures 1A and 1C).

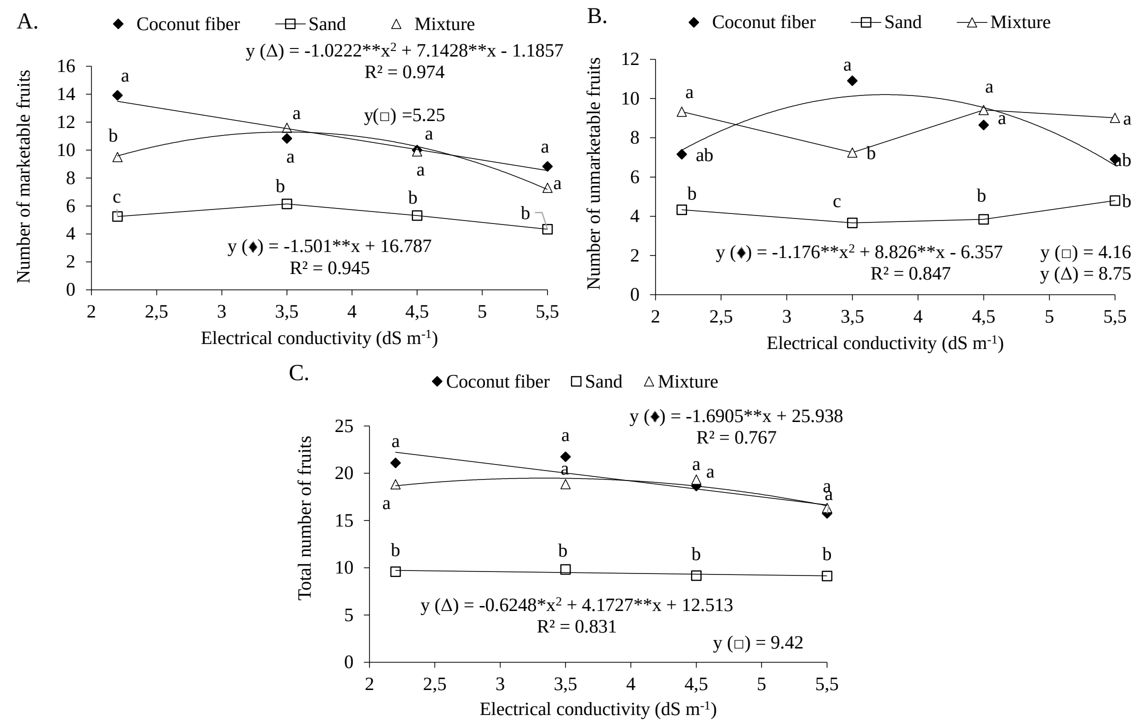

Figure 1. Number of marketable fruits (A), number of unmarketable fruits (B) and total number of fruits (C) of bell pepper plants grown in different substrates and fertigated with salinized nutrient solutions (uppercase letters represent the effect of the substrates on each salinity). Mossoró, UFERSA, 2021.

The plants grown in the mixture substrate showed quadratic responses in relation to an increase of CE for NMF (Figure 1A) and TNF (Figure 1C). The highest NMF was verified in CE 3.49 dS/m (11.29 fruits), equivalent to an increase by 17.86% in relation to NMF obtained in the lowest salinity level (9.58 fruits). For TNF, the highest value was verified in salinity 3.33 dS/m (19.47 fruits), increasing 4.34% in relation to the lowest salinity tested (2.2 dS/m).

The authors noticed no effect of increasing CE in the nutrient solution on NMF and TNT in plants grown in sand, showing average values ranging from 5.25 to 9.42 fruits/plant, for NMC and TNT, respectively (Figures 1A and 1C). This fact occurred, probably, due to lower moisture retention capacity of this substrate, providing lower salinity effect.

The absence of salinity effect on NMF and TNF is due to, probably, two factors. First, because of the lowest fruit set index, reducing plant competition; as the number of fruits increases, the size of these fruits decreases and, therefore, the fruit weight also decreases, since the competition for photoassimilates tends to be greater as the plant needs to translocate photoassimilates to a greater number of fruits (Lins *et al.*, 2013). The second factor is related to the greater macroporosity of the sand, which provides greater capacity to leach salts accumulated in the substrate. Drainage is important, since it renews the solution contained in the substrate and avoids salinization by leaching nutrients and other elements which were not absorbed by the plants in each fertigation performed (Wamser, 2017).

In these two variables, the authors observed that despite the fact that

NMF and TNF showed greater reductions in relation to salinity stress in plants grown in coconut fiber, this substrate still presents values which are similar to the ones obtained in plants grown in mixture, probably, due to a larger quantity of fruits produced by the plants grown in coconut fiber substrate.

Several studies have shown a reduction in number of bell pepper fruits grown under salinity stress, both in semi-hydroponic system (Oliveira *et al*., 2018; Silva *et al*., 2020) or in soil (Abdelaal *et al*., 2020). A decrease in number of fruits grown under salinity stress is justified because salinity negatively affects the water and nutrient uptake by the plants, reducing photosynthetic rate, increasing cell death, ovule abortions, resulting in smaller number of fruits and reducing the production in higher salinity levels (Abdelaal *et al*., 2020).

Substrates differed in relation to number of unmarketable fruits (NUF) according to salinity level applied. No significant difference between coconut fiber and mixture in salinity levels 2.2; 4.5 and 5.5 dS/m was noticed. These results were higher than the values verified in plants grown in sand. In salinity 3.5 dS/m, coconut fiber stood out, being superior in 50.48 and 198.08%, when compared with mixture and sand, respectively (Figure 1B).

Evaluating the effect of electrical conductivity on NUF, a significant quadratic response was verified only in coconut fiber. The highest NUF was noticed in salinity 3.75 dS/m (10.20 fruits), equivalent to an increase by 38.47%, in relation to the value obtained in the lowest salinity (7.36 fruits). We also observed that NUF decreased from CE 3.75 dS/m on, probably due to a reduction in number of total fruits in these higher salinity levels. No effect of an increase of electrical conductivity on NUF in plants grown in sand and mixture was observed, with averages of 4.16 and 8.75 fruits (Figure 1B).

The lack of response for this variable (NUF) in sand and mixture is probably due to a greater aeration of these substrates when compared to coconut fiber. Sand is a substrate which presents low water retention capacity, favoring leaching salts in the root zone, making saline solutions be in contact with plants for less time, unlike coconut fiber, which has high moisture retention, resulting in more unmarketable fruits (Wamser, 2017).

We still highlight that fruits were not thinned, and that, probably, salinity of nutrient solutions and larger number of fruits per plants have contributed to a larger quantity of small fruits (unmarketable) in all substrates.

An increase in quantity of unmarketable fruits grown under salinity stress was related by Silva *et al*. (2020). A lower quantity of marketable fruits may occur in relation to a greater quantity of fruits showing defects and/or higher fruit abortion rate caused by physiological changes resulted in high salt concentrations in nutrient solutions, such as blossom-end-rot (Oliveira *et al*., 2018).

Rubio *et al*. (2011) verified that CE >2.8 dS/m, for cultivation using substrate, increases the incidence of blossom-end-rot in bell pepper fruits, increasing the quantity of unmarketable fruits. This occurs due to the fact that in higher salinity levels, a lower calcium uptake by plants is noticed, resulting in a nutritional imbalance and, consequently, a lower availability of this nutrient in fruits. This physiological disturbance was also reported by Silva *et al*. (2020).

Combined with salinity stress, climatic conditions also contribute to a greater quantity of unmarketable fruits, mainly concerning high luminosity and temperatures, such as the ones found in Brazilian northeast. These facts result in accelerated fruit growth and higher shoot transpiration rate, resulting in a lower calcium flow into fruits (Navarro *et al*., 2010).

Commercial production (MP) differed among substrates for all salinity levels applied. At salinity 2.2 dS/m, coconut fiber provided higher values (947.27 g/plant), being superior in 165.81 and 51.30% in relation to values obtained in sand (356.37 g/plant) and mixture (626.06 g/plant). At salinity level 3.5 dS/m, coconut fiber and mixture did not differ between each other, being the mixture substrate superior in 40.07% when compared with sand. In CE 4.5 dS/m, coconut fiber was superior in 46.21% in relation to sand, which did not differ from mixture. At the highest salinity (5.5 dS/m), coconut fiber was superior to sand in 268.26% (Figure 2).

Coconut fiber substrate provided greater commercial productions in all salinity treatments. The good performance observed in cultivation using coconut fiber is related to its structure and physical-chemical properties, presenting high water retention capacity, aeration of the growing medium and root growth stimulation (Silva *et al*, 2021).

According to Silva *et al*. (2020), the reduction in marketable bell pepper fruit production grown under salinity stress is also caused by the reduction of the number of marketable fruits and size, as well as it was observed in this present study. Moreover, the decrease in marketable fruit production is closely related to the greater incidence of blossom-end-root in fruits, resulted by a Ca deficiency in relation to excess Na^+, due to an antagonistic effect between these elements (Rubio *et al*., 2011).

For the average marketable fruit mass (AMFM) no significant difference among the substrates was noticed (81.18 g). The total production (TP) showed the highest value in coconut fiber substrate, surpassing 124.33 and 25.62% the results in sand and mixture substrates, respectively (Table 2).

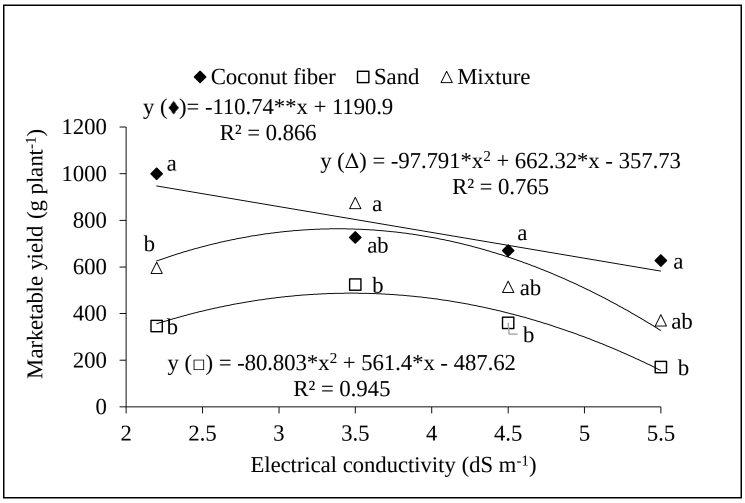

Figure 2. Marketable production (MP) of bell pepper plants grown under salinity stress in different substrates (lowercase letters represent the effect of the substrates on each salinity). Mossoró, UFERSA, 2021.

Table 2. Average values for average marketable fruit mass (AMFM) and total production (TP) of bell pepper plants grown under salinity stress in different substrates. Mossoró, UFERSA, 2021.

Substrates	**MFC (g/fruit)**	**TP (g/plant)**
Coconut fiber	85.91 a	1092.48 a
Sand	82.27 a	486.99 c
Mixture	75.36 a	869.62 b

Averages followed by the same letter, in the columns, do not differ from each other by Tukey test ($p<0.05$).

The average marketable fruit mass (AMFM) was quadratically affected with the increase in salinity in the nutrient solution, regardless of the substrate used. The highest value for AMFM occurred at salinity level 3.28 dS/m (90.68 g/frut), corresponding to an increase in 7% in relation to AMFM obtained in the lowest salinity level (84.75 g/frut). Using the electrical conductivity 5.5 dS/m, AMFM was 66.18 g/fruit, reducing 37.01% in relation to the highest value in CE 3.28 dS/m (Figure 3A).

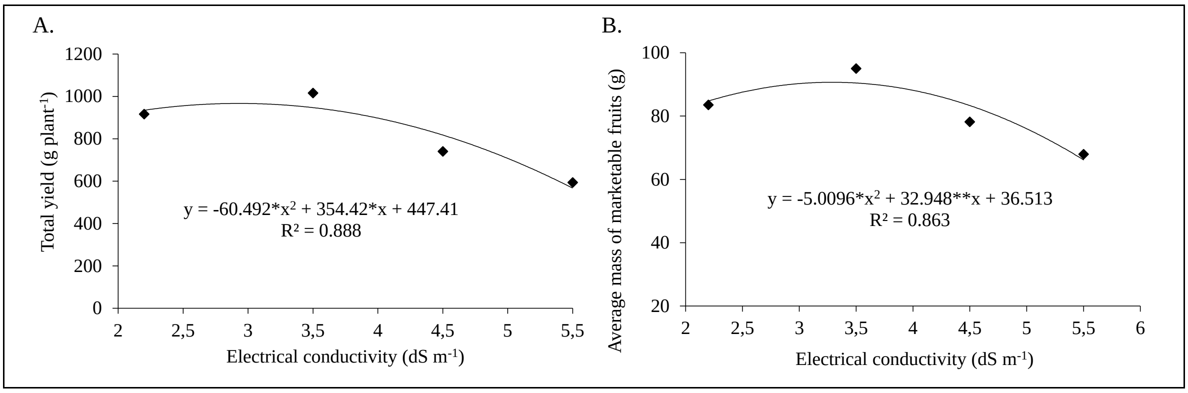

Figure 3. Total production (A) and average marketable fruit mass (B) of bell pepper plants grown in different substrates and fertigated with salinized nutrient solutions. Mossoró, UFERSA, 2021.

Quadratic response for the average marketable bell pepper fruit mass in relation to an increase of salinity was also related by Silva *et al.* (2020). Lima *et al.* (2017) showed that the average bell pepper fruit mass grown in coconut fiber was linearly reduced with the increase of salinity levels similar to this study.

Reductions in size and mass of the fruits are consequences of physiological and biochemical changes in plants grown under salinity stress conditions (Munns & Tester, 2008) and may vary in relation to the cultivar, different salts and salt concentration. Salinity stress affects the photosynthetic process of plants, reflecting in a lower growth and development, as well as a decrease in photoassimilate translocation into fruits for better adapting to salinity stress, which results in smaller fruits

(Munns & Tester, 2008; Souza *et al*., 2023).

In relation to the total production (TP), the authors verified quadratic response for an increase of salinity in nutrient solutions, with the greatest TP (966.54 g/plant) obtained in CE 2.92 dS/m, whereas the smallest TP (566.83 g/plant) was noticed at salinity 5.5 dS/m, corresponding to a reduction in 41.35% (Figure 3B). Other authors also verified this same behavior in bell pepper, authors such as Lima *et al*. (2017) and Silva *et al*. (2020).

Fruit is the most salt-sensitive plant organ. The compromise of pollen grain viability due to increased salinity causes fruit abortion. Nevertheless, when the fruit abortion is not observed, the plant produces smaller fruits, showing lower mass and consequent reduction in total production (Silva *et al*., 2020).

Post-harvest quality

Soluble solid content (SS) presented significant response for interaction between substrate and salinity ($p<0.05$), as well as titratable acidity (TA), vitamin C (VITC) and ratio SS/TA which significantly responded to the interaction between substrate and salinity at 1% probability. Fruit firmness (FIRM) showed significant response only for salinity ($p<0.05$).

We verified no significant difference considering the substrates at salinity levels 2.2; 3.5 and 4.5 dS/m in relation to soluble solid content (SS), averages of 4.81; 5.10 and 4.99ºBrix, respectively. For the highest salinity level (5.5 dS/m), the fruits harvested in plants grown in sand showed SS superior in 44.44% comparing with the ones obtained in mixture. Moreover, we observed that SS contents obtained in fruits of plants grown in mixture and coconut fiber substrates did not significantly differ (Figure 4A).

SS was affected by salinity only in plants grown in sand substrate, showing quadratic response. The highest SS was observed at salinity 5.5 dS/m (6.40ºBrix), representing an increase in 48.65% in relation to the lowest SS (4.31ºBrix), in CE 3.28 dS/m. For coconut fiber and mixture, no significant response concerning an increase of salinity was noticed. The obtained averages were 4.98 and 5.12ºBrix, respectively (Figure 4A).

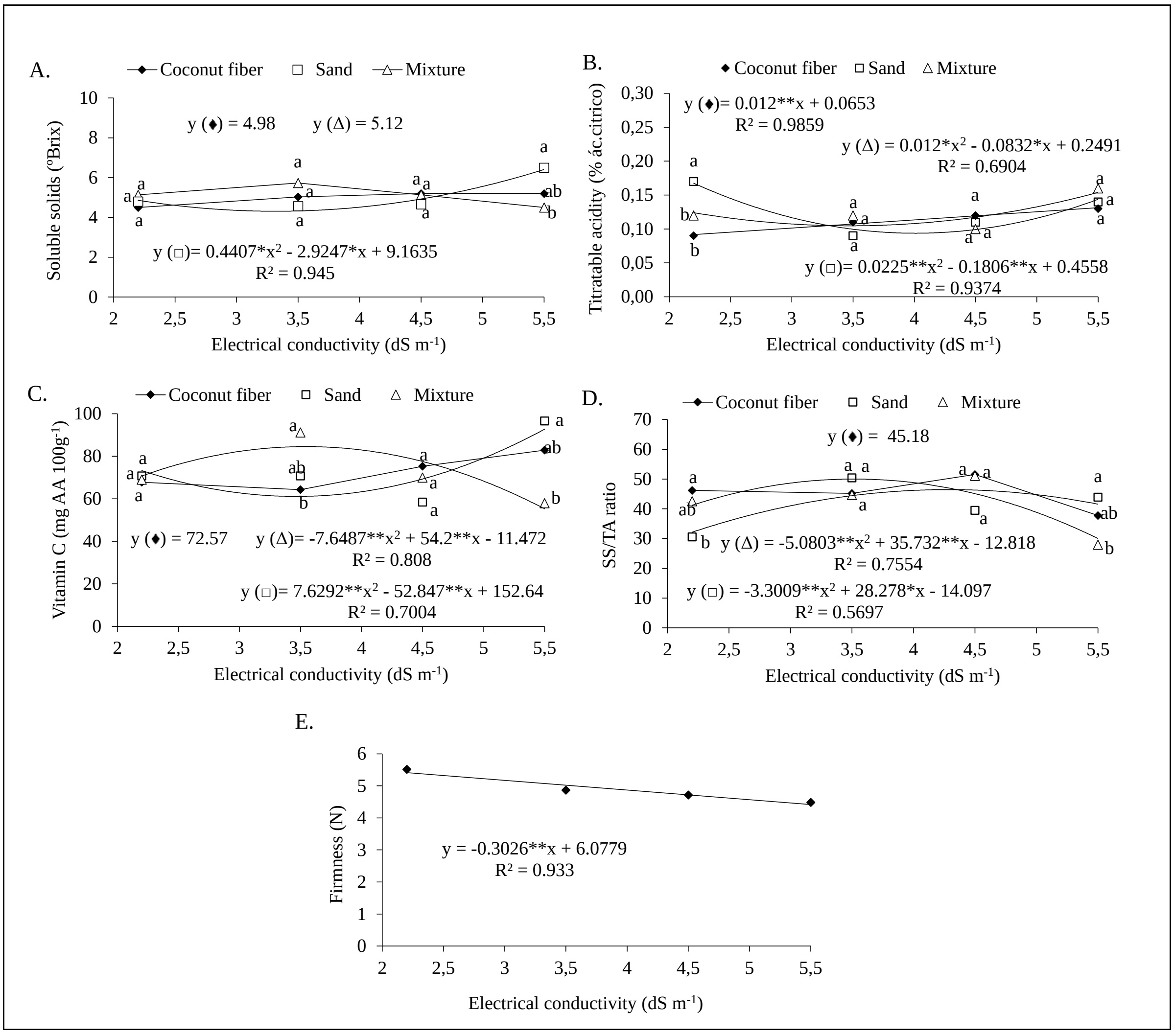

Figure 4. Soluble solid content (A), titratable acidity (B), vitamin C (C), SS/AT ratio (D) and fruit firmness (E) of bell pepper plants grown under salinity stress in different substrates (lowercase letters represent the effect of the substrates on each salinity). Mossoró, UFERSA, 2021.

In this study, we noticed no variation in bell pepper SS caused by different substrates up to CE 4.5 dS/m. Moreover, SS values found are within the same range of values reported in other studies with bell pepper, as in Carvalho *et al*. (2019) who found SS ranging from 4.35 to 5.18ºBrix.

Soluble solid content (SS) is an important trait related to post-harvest quality of bell pepper plants, since it presents sugar and acid content in the fruits, considering that the higher value of SS, more tasteful the fruit is and, consequently, the greater the consumer market interest (Oliveira *et al*., 2015).

According to Pereira *et al*. (2017), the highest soluble solid content in fruits, even in plants irrigated using higher salinity water, is due to a decrease of average fruit mass, resulting in a concentration of photoassimilates. Another fact which can contribute to increase SS content concerning the response to salinity stress is related to a reduction of the osmotic potential of the solution, which reduces water uptake, reducing water content in fruits and increasing solute concentration (Oliveira *et al*., 2015).

In relation to titratable acidity (TA), a significant difference among the substrates was noticed only at the lowest salinity level (2.2 dS/m), when sand substrate showed values superior in 66.66 and 25.0%, comparing with the coconut fiber and mixture substrates, respectively. No significant difference among the substrates at other salinity levels was noticed, showing TA values of 0.10; 0.10 and 0.14% citric acid, respectively, at salinity levels 3.5; 4.5 and 5.5 dS/m (Figure 4B).

Evaluating the salinity effect on TA, the authors verified significant positive linear response for coconut fiber. For sand and mixture, quadratic behavior was noticed. In coconut fiber, an increase in TA was noticed with an increase of electrical conductivity, being the highest AT (0.13% citric acid) obtained using CE 5.44 dS/m, which represents an increase in 42.42% in relation to the value obtained at salinity level 2.2 dS/m (0.09% citric acid). For sand substrate, the highest value of TA was obtained at salinity level 2.2 dS/m (0.16% citric acid), whereas the lowest TA was noticed in CE 4.01 dS/m (0.09% citric acid), resulting in a reduction of 9.33%. In mixture substrate, the highest TA (0.15% citric acid) was verified at the highest level of salinity (5.5 dS/m), increasing 24.45% in relation to the lowest salinity level (2.2 dS/m) (Figure 4B).

Salinity effect on titratable acidity of fruit has not been well understood yet. Ahmadi & Souri (2020) verified a reduction in acidity in pepper fruits in response to salinity stress. On the other hand, Damasceno *et al*. (2021) observed an increase in AT in eggplant fruits at higher salinity levels, as it was noticed in this study for coconut fiber and mixture substrates.

The increase in titratable acidity of fruits shall be related to an increase in Na^+ and/or Cl^- content in fruit, since these are the only ions which increase in salinity, while a reduction in accumulation of potassium in fruits is verified. According to Agius *et al*. (2022), in these conditions, the proportion of metal ions and counter-anions becomes unbalanced, which may be responsible for the lower pH and increased titratable acidity.

For vitamin C (VITC), no significant difference among the substrates at salinity levels 2.2 and 4.5 dS/m was verified, and averages of 69.21 and 75.41 mg/100 g, respectively, were observed. At salinity level 3.5 dS/m, the highest value of VITC was verified in fruits of plants grown in mixture, being superior in 41.85% compared to the ones obtained in coconut fiber, considering that neither of these substrates differed from sand. At the highest salinity level (5.5 dS/m), no significant difference between values of VIT C obtained in coconut fiber and sand was noticed, being the value found in sand superior in 66.81% in relation to the mixture of the substrates (Figure 4C).

VITC content was affected by salinity in sand and mixture substrates. For sand, the highest VITC content in fruits (92.76 mg/100 g) was also observed in plants grown at higher salinity (5,5 dS/m), increasing 26,55% when compared with lower salinity level, in which the fruits presented VITC content of 73.3 mg/100 g. The authors noticed, in mixture substrate, quadratic response differently from what was observed in sand. The highest VITC content was verified at salinity level 3.54 dS/m (84.54 mg/100 g), whereas the lowest VITC content was observed at higher salinity level (55.25 mg/100 g). Salinity did not affect VITC content in bell pepper fruits in plants grown in coconut fiber substrate, showing average vitamin C of 72.57 mg/100 g (Figure 4C).

Studying bell pepper cultivation under salinity stress under hydroponic system, Amalfitano *et al*. (2017) verified an increase in VITC content as the electrical conductivity of the nutrient solution increased. Ahmadi & Souri (2020) reported a reduction in vitamin C in bell pepper fruits when plants were submitted to salinity, though.

An increased tolerance of plants to salinity stress occurs by accumulation of osmoprotective agents to induce osmotic adjustment in cells. Among the osmolytes produced, a higher concentration of proteins, sugars and amino acids was verified (Ahmadi & Souri, 2020). Antioxidant activity is also increased, which explains the greater amount of ascorbic acid at 5.5 dS/m.

No significant difference in relation to ratio SS/TA among the substrates at intermediate salinity levels (3.5 and 4.5 dS/m) was noticed, averages of 46.77 and 47.4, respectively, were verified. At salinity level 2.2 dS/m, the value obtained in coconut fiber was superior in 51.17% in relation to the value obtained in sand. However, at the highest salinity level (5.5 dS/m), sand substrate provided ratio SS/TA superior in 57.26% in comparison with mixture substrate, and both did not show any difference regarding to the ratio provided by coconut fiber substrate (Figure 4D).

Electrical conductivity of the nutrient solution affected SS/TA ratio for the fruits harvested in plants grown in sand and mixture substrates. In sand, the highest SS/TA (46.46) was obtained at salinity level 4.28 dS/m, increasing 44.58% in relation to the lowest salinity level (2.2 dS/m). For mixture, the highest SS/TA ratio (50.01) occurred in CE 3.51 dS/m, resulting in an increase of 21.37%, in relation to SS/TA ratio obtained at salinity level 2.2 dS/m (41.27). For coconut fiber, no significant response was noticed related to an increase in salinity, obtaining an average SS/TA of 45.18 (Figure 4D).

For bell pepper crop, no quality range for SS/TA has been verified yet; however, the higher the SS/AT, the better and smoother the flavor of the fruit is, due to a better balance of sugars and acids. The lower the SS/TA, the more acidic the flavor is, according to Paiva *et al*. (2018) in tomato and Damasceno *et al*. (2021) for eggplant crop.

For fruit firmness (FIRM), we verified that as the salinity of the nutrient solutions increased, fruit firmness decreased linearly. The greatest FIRM (5.41 N) was found in the lowest salinity (2.2 dS/m). In the highest salinity (5.5 dS/m), FIRM was 4.44 N, showing a reduction in 18.45% in relation to the highest value (Figure 4E).

Hand *et al*. (2021) also observed tendency for reducing firmness with an increase in salinity in pepper fruits. Firmness is an important variable considering the preservation of the fruit after harvesting, in order to avoid injuries caused by handling. Therefore, the greater the firmness, the less risk of fruit damage.

For some authors, reduction in fruit firmness in response to salinity stress occurs, probably, due to a reduction in calcium concentration, which is a nutrient closely related to maintaining fruit quality (Hand *et al*., 2021).

In short, coconut fiber and mixture are the most recommended substrates for producing bell pepper plants under salinity stress. Moreover, bell pepper can be produced in coconut fiber or coconut fiber and sand mixture (1:1) using water with salinity up to 3.5 dS/m and that the type of substrate has little influence on the quality of bell pepper fruits produced under salinity stress up to salinity 4.5 dS/m.

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