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Production and quality of mini watermelon under salt stress and K^+/Ca^{2+} ratios[1]

Produção e qualidade de mini melancia submetida ao estresse salino e razões K^+/Ca^{2+}

Aline da S. Alves[2], Francisco de A. de Oliveira[2*], Daisy D. da Silva[2], Sandy T. dos Santos[2], Renata R. T. Oliveira[2] & Helena M. de M. N. Góis[2]

[1] Research developed at Mossoró, RN, Brazil
[2] Universidade Federal Rural do Semi-Árido/Programa de Pós-Graduação em Manejo de Solo e Água, Mossoró, RN, Brazil

HIGHLIGHTS:
Potassium and calcium nutrition is an efficient strategy to reduce the effects of salinity on mini watermelons.
Visual quality as a function of pulp color is increased using saline water and the maximum dose of calcium.
Quality of mini watermelon fruit is not affected when using saline water in the nutrient solution.

ABSTRACT: Nutritional management can be an efficient strategy to mitigate the effects of salinity on fruit production and quality. This study aimed to evaluate the production and quality of fruits of mini watermelon crop, Sugar Baby cultivar, grown in a protected environment, under salt stress and K^+/Ca^{2+} ratios. The study was carried out in a greenhouse, using a randomized block design, 1 + 5 scheme, resulting in six treatments and four replications. Six nutrient solutions were employed, one using low-salinity water, with NaCl (0.5 dS m^{-1}) and standard nutrient solution (S1, control treatment), and the others using salinized water at 5.0 dS m^{-1} (S2) and extra addition of K (S3 = 50% and S4 = 100%) and Ca (S5 = 50% and S6 = 100%). The production (fruit production, longitudinal and transverse diameter of fruit, rind thickness, pulp firmness) and postharvest quality (soluble solids, vitamin C, titratable acidity, and maturation index), in addition to the variables related to the color of the pulp (lightness, chroma index, and Hue angle) were evaluated. The addition of NaCl reduced fruit production, longitudinal, and transverse diameter of fruit, rind thickness, and vitamin C content. Among saline nutrient solutions, extra addition of 50% K (S3) attenuates the deleterious effects of salt stress on the production variables and vitamin C content. Under salt stress, extra addition of 50% K (S3) and 100% Ca (S6) intensifies the red color of the pulp.

Key words: *Citrullus lanatus*, salinity, potassium supplementation, calcium supplementation

RESUMO: O manejo nutricional pode ser uma estratégia eficiente para mitigar os efeitos da salinidade na produção e qualidade de frutos. O objetivo deste trabalho foi avaliar a produção e qualidade de frutos de mini melancia, cultivar Sugar Baby, cultivado em ambiente protegido, sob estresse salino e relações K^+/Ca^{2+}. O estudo foi realizado em casa de vegetação, em delineamento de blocos casualizados, em esquema 1 + 5, resultando em seis tratamentos e quatro repetições. Foram aplicadas seis soluções nutritivas, uma utilizando água de baixa salinidade (0,5 dS m^{-1}) e solução nutritiva padrão (S1, tratamento controle) e as demais utilizando água salinizada com NaCl, a 5,0 dS m^{-1} (S2) e adição extra de K (S3 = 50% e S4 = 100%) e Ca (S5 = 50% e S6 = 100%). Foram avaliadas as variáveis de produção (produção de frutos, diâmetro longitudinal do fruto, diâmetro transversal do fruto, espessura da casca, firmeza da polpa) e qualidade pós-colheita (sólidos solúveis, vitamina C, acidez titulável e índice de maturação), além das variáveis referentes a cor da polpa (luminosidade, croma e ângulo de Hue). A adição de NaCl reduziu a produção de frutos, diâmetro longitudinal dos frutos, diâmetro transversal dos frutos, espessura da casca e vitamina C. Entre as soluções nutritivas salinas, a adição extra de K a 50% (S3) atenua os efeitos deletérios do estresse salino nas variáveis de produção e o teor de vitamina C. Sob estresse salino, a adição extra de K em 50% (S3) e Ca em 100% (S6) intensifica a coloração vermelha da polpa.

Palavras-chave: *Citrullus lanatus*, salinidade, suplementação potássica, suplementação cálcica

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* Corresponding author - E-mail: thikaoamigao@hotmail.com
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Introduction

Watermelon (*Citrullus lanatus* L.) is one of the main fruits in the world in volume of production and is among the ten most exported horticultural products, driving approximately US$ 43,891,165 in 2019 (IEA, 2020). Among the most produced genetic materials, the Sugar Baby cultivar stands out in the mini-fruit segment. It has desirable characteristics such as intense reddish pulp color and high lycopene content (Mahamat et al., 2021).

Watermelon crop is classified as moderately tolerant to salinity, with the potential to reach maximum development up to the salinity threshold of 2.5 dS m^{-1} in the soil saturation extract (Ayers & Wescott, 1999). However, this tolerance may vary according to genetic material, environmental conditions, and cultivation system, being increased in hydroponic cultivation due to the lower matric potential of the substrate (Silva Junior et al., 2019; Ó et al., 2020).

In mini watermelons, studies have shown that salt stress causes physiological changes such as reduced transpiration, photosynthesis, stomatal conductance, and internal concentration of CO_2 (Lima et al., 2020; Silva et al., 2021). These effects cause a loss in production mainly due to the reduction in fruit size (Ó et al., 2020).

Several strategies have been studied to reduce salt stress and enable the use of inferior quality water, especially regarding nutritional management with Ca and K (Santos et al., 2018; Silva et al., 2020; Oliveira et al., 2021), as the absorption of these nutrients is reduced under Na-rich conditions (Silva Junior et al., 2020).

In view of this, the aim of this study was to evaluate the production and quality of fruits of mini watermelon crop, cultivar Sugar Baby, cultivated in a protected environment under salt stress and K^+/Ca^{2+} ratios.

Material and Methods

An experiment was carried out from July to October 2019 in a greenhouse belonging to Universidade Federal Rural do Semi-Árido (UFERSA), in Mossoró, Rio Grande do Norte, Brazil (05° 12' 3.63" S; 37° 19' 38.29" W, mean altitude of 18 m). The greenhouse has an area of 126 m^2, length 18 m, width 7 m, an upper cover of transparent low-density polyethylene film, a transparent light diffuser (LDPE - Low- Density Polyethylene) with 150 µm thickness, treated against ultraviolet rays.

The climate in the region, according to the Köppen-Geiger classification, is BSwh' (hot and dry) with very irregular rainfall, with an annual mean rainfall of 673.9 mm, mean temperature of 27.4 °C, mean relative air humidity of 68.9%, mean daily insolation of 7.83 hours, and mean wind speed of 0.84 m s^{-1} (Alvares et al., 2013).

The experiment was carried out in randomized block design, in 1 + 5 scheme, resulting in six treatments and four replications. Six nutrient solutions were employed, one using low-salinity water (0.5 dS m^{-1}) and standard nutrient solution (S1, control treatment) and the others using saline water at 5.0 dS m^{-1} (S2), obtained by dissolving NaCl, and extra addition of K (S3 = 50% and S4 = 100%) and Ca (S5 = 50% and S6 = 100%). Each treatment had four replications, and the experimental unit consisted of four pots with four plants each, in a total of 96 pots.

The nutrient solutions S1 and S2 contained the concentrations of K and Ca as indicated by Campagnol et al. (2012) for the cultivation of mini watermelons in a greenhouse. The other nutrient solutions differ regarding the concentrations of K and Ca, according to each treatment.

Doses of K and Ca used in the present study are presented in Table 1. The amounts of nitrogen, phosphorus, and magnesium were the same in phases I and II, and their values were 130, 6, 74.4, and 21.9 g 100L^{-1}, respectively. In phase III the values of nitrogen, phosphorus, and magnesium were 179.7, 55.5, and 44.2 g 1000L^{-1}. For sulfur, the values were 27.6 g 1000L^{-1} in phase I, 45.6 g 1000L^{-1} in phase II, and 55.8 g 1000L^{-1} in phase III. For the addition of micronutrients, Rexolin iron and Rexolin compound were used, with 30 g of product for each 1000 L of solution according to the manufacturer's instructions. After preparing the nutrient solutions, their electrical conductivity values were 3.2, 7.1, 8.0, 8.5, 7.3, and 7.9 dS m^{-1}, respectively.

The experiment was implemented by direct sowing in pots and placing five seeds of mini watermelon, cultivar Sugar Baby, in each pot. The pots used had dimensions of 0.33 m height, 0.30 m upper diameter, and 0.20 m lower diameter, with 10 dm^3 volume. In the lower part of the pot, a drainage system was placed, consisting of a layer of gravel number 1 and geotextile blanket. The pots were filled with coconut fiber substrate and washed sand (1:1, on volume basis) and were arranged at a spacing of 0.45 m between plants and 1.20 m between rows of plants.

The nutrient solutions were distributed by an independent irrigation system, one for each nutrient solution. Each system consisted of a 0.5 hp motor pump, 16 mm polyethylene distribution lines, and microtube emitters with an internal diameter of 1.5 mm and a flow rate of 7 L h^{-1}. Fertigation frequencies varied according to the needs of each stage of crop development. For the first phase of development, fertigation was carried out five times a day, lasting 1 min, in the second phase seven times a day, lasting 2 min, and in the third phase

Table 1. Concentrations (mg L^{-1}) of potassium and calcium for the preparation of the base nutrient solution used in the experiment

Nutrients (g 1000L^{-1} of water)	S1	S2	S3	S4	S5	S6
	Phase I – From transplanting to beginning of flowering					
Potassium	81.3	81.3	121.9	162.6	81.3	81.3
Calcium	94	94	94	94	141	188
	Phase II – From beginning of flowering to fruit development					
Potassium	122.3	122.3	183.4	244.6	122.3	122.3
Calcium	94	94	94	94	141	188
	Phase III – From beginning of fruit development to harvest					
Potassium	159.9	159.9	239.8	319.8	159.9	159.9
Calcium	80	80	80	80	120	160

S1 – Standard nutrient solution, control treatment (Campagnol et al., 2012); Nutrient solution using brackish water (5.0 dS m^{-1}); S3 – Nutrient solution using brackish water and extra addition of 50% K; S4 – Nutrient solution using brackish water and extra addition of 100% K; S5 – Nutrient solution using brackish water and extra addition of 50% Ca; S6 – Nutrient solution using brackish water and extra addition of 100% Ca of crop development, four times a day, lasting 1 min. In all irrigation events, there was always drainage of nutrient solution to avoid excessive accumulation of salts in the root zone.

Wooden stakes and stainless-steel wires were installed parallel to each row of plants to help guide the branches in a vertical direction and in the staking, which was made with plastic ribbons. These plastic ribbons were tied to the plant's collar and fixed to the steel wires vertically, so that, as the stems grew, they were twisted around the ribbon. Pruning was performed throughout the cycle as needed.

Pollination was performed manually, always in the early hours of the morning, considering that, during the day, pollen grains have reduced viability (Abreu et al., 2008). When the fruit was fixed in the desired position (between 8 and 14 internodes, from the collar of the plant), thinning was performed, leaving only one fruit per plant. The fixed fruits, when they reached approximately 4.0 cm in diameter, were supported by nylon nets (bags), which were tied to the horizontal wires that were fixed above the planting row (Campagnol et al., 2012).

The fruits were harvested 72 days after sowing when they reached the point of harvest. After harvesting, the fruits were transported to the Laboratório de Pós-Colheita at UFERSA to be analyzed for production and quality.

The biometric characteristics assessed were: fruit production (PROD): determined using a digital scale, expressed in g per fruit; longitudinal (LDFR) and transverse diameter of fruit (TDFR): measured with an analog caliper at the longest and shortest length, respectively (cm); rind thickness (PT): measured with a digital caliper (cm).

The colorimetric analysis was performed in the central part of the pulp and determined with the aid of a Konica Minolta CR 400 colorimeter, using the L*a*b* color space, also known as CIELAB color space, where the L* coordinate indicates the lightness, a* is the red/green coordinate (-a is green/ + a is red) and b* is the yellow/blue coordinate (-b is blue/ +b is yellow). The Hue angle (arc-tang (a,b) x 18/ π) and the Chroma index $((a^2 + b^2)^{0.5})$ were determined based on a* and b* coordinates.

The quality characteristics assessed were: pulp firmness (FIRM): determined with the aid of a digital penetrometer (McCormick model FT. 327), (N); soluble solids (SS): determined with the digital refractometer model ATAGO PR-100, (°Brix); vitamin C (Vit C): determined by neutralization titration with DFI solution (2.6 dichlorophenolindophenol 0.02%), in accordance with Strohecker & Henning (1967), (in mg of vitamin C $100g^{-1}$ of pulp); titratable acidity (TA), determined by the titration method, using 10 g of fruit juice, adding 100 mL of distilled water, then proceeding with the titration using sodium hydroxide (0.02N) and phenolphthalein as indicator, showing a slightly pink color after turning; and maturation index (MI): calculated by the SS/TA ratio.

Data obtained were subjected to analysis of variance by the F test at $p \leq 0.05$ and the means referring to saline solutions were compared by the Tukey test at $p \leq 0.05$. The saline solutions were compared to the standard solution (control) by the Dunnett test at $p \leq 0.05$. Statistical analyses were performed using the SISVAR software (Ferreira, 2019).

Results and Discussion

There was a significant effect of the treatments for the variables fruit production (PROD), longitudinal (LDFR) and transverse diameter (TDFR), and rind thickness (RT) ($p \leq 0.05$), with no significant response ($p > 0.05$) for pulp firmness (FIRM) (Table 2).

The addition of NaCl in the nutrient solution (S2) caused a reduction in all production variables compared to the control treatment, regardless of K and Ca concentrations, except for FIRM. These reductions were around 46.39, 20.01, 19.25, and 17.35% for PROD, LDFR, TDFR, and PT, respectively (Table 2).

These results partly corroborate those presented by other authors, who also found a reduction in the size and weight of fruits of mini watermelon due to increased salinity, whether in soil cultivation (Suárez-Hernández et al., 2019) or in hydroponics (Ó et al., 2020). This reduction occurs mainly because of the lower water potential in the substrate, in response to the osmotic effect, thereby reducing the absorption of water and nutrients and, consequently, the production of plants.

When considering that the crop was conducted with one fruit per plant, the effect of salt stress on production is directly related to the size of the fruit. Reduction in fruit size by salt stress is a consequence of the reduction in water potential caused by excess salts in the medium. This situation imposes a greater expenditure of energy to maintain the metabolic

Table 2. Summary of the F-test and mean values for biometric characteristics in fruits of mini watermelon grown in a protected environment fertigated with saline nutrient solutions (SNS) enriched with potassium and calcium

Sources of variation	DF	F-test				
		PROD	LDFR	TDFR	RT	FIRM
Blocks	3	ns	ns	ns	ns	ns
Treatments	5	**	**	**	**	ns
CV (%)		14.40	6.36	5.98	8.30	20.7
Nutrient solutions		Mean values				
		PROD	LDFR	TDFR	RT	FIRM
S1 - Control treatment		1903.75	15.750	16.00	0.98	7.42
S2 – SNS		878.00 b#	11.16 b#	12.43 a#	0.78 a#	8.79 a
S3 – SNS + 50% K		1283.00 a#	13.62 a#	13.81 a#	0.84 a#	7.95 a
S4 – SNS + 100% K		1002.00 ab#	12.69 ab#	12.62 a#	0.82 a#	8.58 a
S5 – SNS + 50% Ca		908.86 b#	12.33 ab#	12.43 a#	0.77 a#	8.48 a
S6 – SNS + 100% Ca		1030.62 ab#	13.19 a#	13.31 a#	0.85 a#	8.03 a

ns; *; ** - Not significant, significant at 0.05 and 0.01 probability levels, respectively. Means followed by # differ from the control treatment by Dunnett's test ($p \leq 0.05$). Means followed by the same letters in the columns did not differ by Tukey's test ($p \leq 0.05$). SNS - Saline nutrient solutions; S1 - Control treatment (Campagnol et al., 2012); PROD – Fruit production (g $plant^{-1}$); LDFR – Longitudinal diameter of fruit (cm): TDFR – Transverse diameter of fruit (cm); RT – Rind thickness (cm); FIRM – Pulp firmness (N) activities of plants and, consequently, induces the formation of fruits with lower mass (Silva et al., 2019).

When analyzing PROD, it is verified that the increase in the concentration of K by 50% (S3), as well as the increase in the concentration of Ca by 100% (S6) led to a significant increase in this variable, promoting gains of 46.12 and 17.38%, respectively, in comparison with the values obtained in the combination S2, corresponding to the concentrations of K and Ca considered control treatment. LDFR was also affected by K and Ca concentrations in the saline nutrient solution, with higher values occurring in the combination with the addition of 50%K (S3) and 100% Ca (S6), being 22.04 and 18.19% higher, respectively, in comparison with fruits obtained with the control nutrient solution (Table 2).

These results show the importance of adequate potassium and calcium nutrition in mini watermelon for conditions under which it is necessary to use saline water in the preparation of the nutrient solution, evidencing that under these conditions the plant has greater requirement for these nutrients. Varying effects of K and Ca doses, under saline conditions, have also been observed by other authors, working with tomato (Oliveira et al., 2021), eggplant (Santos et al., 2018), and bell pepper (Silva et al., 2020).

Potassium fertilization should also be considered as an alternative capable of increasing the tolerance of plants to salinity, since K is vital for several biological processes in cells, such as enzymatic activation, respiration, photosynthesis, and improvement of water balance. Under salt stress, K^+ helps in maintaining ionic homeostasis and regulating osmotic balance (Hasanuzzaman et al., 2018).

Silva et al. (2022), when assessing the effect of K doses and irrigation strategies with saline water varying along the crop cycle, did not observe any interaction between the factors for yield parameters. These authors verified that the use of saline water caused a reduction in production and that the addition of 100% of K in the adopted recommendation promoted the highest yield. However, these authors studied cultivation in soil, which may have altered the crop response to potassium fertilization under saline conditions.

An increase in pulp firmness in response to water salinity occurs due to lower water absorption by the plant as a function of osmotic pressure (Taiz et al., 2017). Calcium interacts with pectin and helps preserve fruit firmness by maintaining cell wall integrity (Mohebbi et al., 2020). Regarding the effect of K, Preciado-Rangel et al. (2018) observed that it promotes greater firmness and resistance of melon tissues.

Regarding the quality and post-harvest variables of the fruits, it was observed that the vitamin C content (VIT C) and chroma index (C*) were affected by the treatments applied ($p \leq 0.05$). For the variables soluble solids content (SS), titratable acidity (TA), maturation index (MI), and for color lightness (L*) and Hue angle (H°) indexes, there was no significant effect of the treatments applied ($p > 0.05$). Salinity, as well as K and Ca concentrations, did not affect the variables SS, TA, MI, L*, and H°, which showed mean values of 8.64 °Brix (SS), 0.11% citric acid (TA), 75.40 (MI), 37.39 (L*), and 45.62 (H°) (Table 3).

These results corroborate those presented by Ó et al. (2020) and Silva et al. (2022), who also found no change in the SS variable in fruits of mini watermelon irrigated with saline water. However, these authors found a significant response for TA and MI variables. Other authors have also found beneficial effects of potassium fertilization on SS in watermelon fruits under salt stress conditions (Gomes et al., 2020; Silva et al., 2022).

K plays an important role in improving chemical constituents in fruits as it is involved in the transport of sugars to other parts of the plant, resulting in improved fruit quality, speeding up the metabolic activity of fruit to increase SS (Khan et al., 2022). However, in the present study, salt stress inhibited the effect of potassium nutrition on SS.

Contents of VIT C in mini watermelon fruits were reduced when saline water was used combined with the highest concentration of K (treatment S4) and with the increase in the concentrations of Ca (treatments S5 and S6), causing losses of 39.13, 26.06, and 36.61%, respectively, compared to the VIT C content obtained in the control treatment. When the effect of K and Ca concentrations in saline solution was analyzed, it was observed that for both nutrients the application of the highest concentrations caused a reduction in this variable, and the highest values were obtained in the combinations S2 and S3 (Table 3).

Reduction in VIT C content in mini watermelon was also observed in response to increased water salinity by Silva et al. (2022) when studying the cultivar Sugar Baby. These authors

Table 3. Summary of the F-test and mean values for quality characteristic and color indexes in fruits of mini watermelon grown in a protected environment fertigated with saline nutrient solutions (SNS) enriched with potassium and calcium

Sources of variation	DF	F-test						
		SS	VIT C	TA	MI	L*	C*	H°
Blocks	3	ns	ns	ns	ns	ns	ns	ns
Treatments	5	ns	**	ns	ns	ns	**	ns
CV (%)		5.53	14.04	8.86	13.60	11.51	5.75	9.65
Nutrient solutions		**Mean values**						
		SS	VIT C	TA	MI	L*	C*	H°
S1 – Control treatment		8.54	11.09	0.11	76.86	36.09	32.37	46.33
S2 – SNS		8.79 a	9.70 a	0.12 a	77.95 a	39.13 a	35.02 ab	46.13 a
S3 – SNS + 50% K		8.89 a	9.48 a	0.12 a	73.78 a	39.79 a	36.62 a#	48.43 a
S4 – SNS + 100% K		9.01 a	6.75 b#	0.13 a	68.58 a	38.31 a	35.77 ab	43.87 a
S5 – SNS + 50% Ca		8.25 a	8.20 ab#	0.11 a	73.25 a	40.50 a	31.94 b	44.64 a
S6 – SNS + 100% Ca		8.83 a	7.03 b#	0.12 a	76.19 a	35.77 a	38.11 a#	41.48 a

ns; *; ** - Not significant, significant at 0.05 and 0.01 probability levels, respectively. Means followed by # differ from the control treatment by Dunnett's test ($p \leq 0.05$). Means followed by the same letters in the columns do not differ by Tukey's test ($p \leq 0.05$). SNS - Saline nutrient solutions; S1 - Control treatment (Campagnol et al., 2012); SS – Soluble solids (°Brix); Vit C – Vitamin C (mg $100g^{-1}$ of ascorbic acid); TA – titratable acidity (% of citric acid); MI – Maturation index; L* - Lightness; C* - Chroma index; H° – Hue angle also observed that an increase in potassium concentration under saline conditions caused greater reductions in the VIT C content.

In the present study, maturation indexes ranged from 68.57 to 77.95, values higher than those observed by Silva et al. (2022), who obtained MI ranging from 38 to 58. MI is indicative of fruit maturation and, therefore, of flavor for most fruits, as it expresses the sweetness/acid balance. This result is consistent with those obtained for the variables SS and TA, as they were also not affected by the treatments applied.

For variables related to pulp color, the values of L* index obtained in this study are close to those observed by Araújo et al. (2016) for diploid watermelon of the cultivar Style, which showed L* index value of 41.3 at harvest. Other authors have found values ranging from 12 to 57, depending on the genetic material, position and sample preparation (Chaves et al., 2013; Oliveira et al., 2019).

The L* coordinate is related to the lightness of the fruit pulp, ranging from 0 (black) to 100 (white), and the lower the L* value, the darker the red color of the pulp. As the fruits obtained in the present study had an L* value lower than 50, they can be classified as more opaque than bright. According to Chaves et al. (2013), L* value is inversely correlated with appearance, so the lower the value, the greater the preference of consumers, who prefer fruits whose pulp has a dark red color.

The hue angle defines the color tone; it is represented by an angle from 0 to 270°. Angles between 0 and 90° are represented by red, from 90 to 180° by green and from 180 to 270° by blue, and the chromaticity, saturation, or intensity of the color (McGuire, 1992). For the range from zero to 90, Asakuma & Shiraishi (2017) proposed the following color classification: yellowish, for Hue > 60; orange, for 51 ≤ Hue ≥ 59; reddish, for Hue < 50. In this context, all fruits analyzed in this study were classified as having red pulp.

The addition of NaCl in the nutrient solution promoted an increase in chroma color index (C*) for the S3 and S6 combinations, with gains of 13.12 and 17.73%, respectively, compared to the value obtained in the control treatment. As for the effect of K and Ca concentrations, the highest C* values were obtained in the S3 and S6 combinations, while the S4 combination led to the lowest C* index (Table 3).

The chroma index is indicative of the homogeneity of the color of the fruit pulp, so the higher its value, the more intense the color. This index is also related to the degree of fruit maturation, as high chroma values are indicative of fruit maturation (Reis et al., 2014).

Reddish-colored fruits are associated with high levels of lycopene, a bioactive compound belonging to the group of carotenoids that have an antioxidant function and bring numerous health benefits (Mahamat et al., 2021). The chroma index has a positive correlation with lycopene content in the watermelon pulp, so both the addition of NaCl in the nutrient solution and the extra addition of 50% K (S3) and 100% Ca (S6) promote an increase in the lycopene content.

Considering that salinity reduces the crop cycle and that all treatments were harvested on the same day, the fruits collected from plants subjected to saline treatments had higher chroma values, indicating a more advanced stage of maturity.

Conclusions

1. Addition of NaCl in nutrient solution reduced production regardless of the extra addition of K and Ca.

2. Among saline nutrient solutions, the extra addition of 50% K increases fruit production and vitamin C content.

3. Under salt stress, nutrient solution concentrations with extra addition of 50% K and 100% Ca intensify the red color of the pulp.

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