ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.10, e277139, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n10e277139

ORIGINAL ARTICLE

Production and fruit quality of Italian zucchini under brackish water irrigation strategies[1]

Produção e qualidade de frutos da abobrinha italiana sob estratégias de irrigação com água salobra

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HIGHLIGHTS:

Zucchini cv. Caserta have greater sensitivity to high salinity of irrigation water during the initial growth stage.
Saline water in germination and initial growth reduces the physical quality and increases the soluble solids of zucchini.
Salinity stress applied during germination and growth reduces the production and water use efficiency of zucchini.

ABSTRACT: Semi-arid regions are subject to irregular rainfall distribution, leading to long periods of drought. Therefore, the only way to achieve and ensure production is through irrigation. However, in these regions, brackish water is predominant, requiring the adoption of irrigation strategies for better utilization. In this context, the objective of present study was to evaluate the production and fruit quality of Italian zucchini subjected to brackish water irrigation strategies during phenological stages. A completely randomized design with five treatments was used: S1 = low-salinity water (0.8 dS m^{-1}) throughout the crop cycle; S2 = high-salinity water (3.0 dS m^{-1}) only during germination and growth stages (0-11 DAS); S3 = high-salinity water (3.0 dS m^{-1}) only during the pre-flowering stage (12-22 DAS); S4 = high-salinity water (3.0 dS m^{-1}) only during the fruiting stage (23-42 DAS); S5 = high-salinity water (3.0 dS m^{-1}) only during the harvesting stage (43-63 DAS), with eight replications. Irrigation with brackish water (3.0 dS m^{-1}) during the pre-flowering and fruiting stages negatively affects the length and diameter of Italian zucchini fruits. The average fruit mass, skin thickness, production, and water use efficiency are reduced when zucchini plants were irrigated with water of higher electrical conductivity during the germination and initial growth stages, while the soluble solids content is increased. Under conditions of high salinity, it is possible to irrigate zucchini crop without loss of fruit quality and production throughout the harvesting stage.

Key words: *Cucurbita pepo*, salinity, water use efficiency, phenological stage

RESUMO: As regiões semiáridas estão sujeitas à distribuição irregular das chuvas, o que ocasiona longos períodos de estiagem. Deste modo, a única maneira de obter e garantir a produção é utilizando a irrigação, porém, nessas regiões, ocorre a predominância de águas de baixa qualidade (salobras), sendo necessário adotar estratégias de irrigação para melhor aproveitamento. Neste sentido, objetivou-se avaliar a produção e qualidade de frutos da abobrinha italiana submetida a estratégias de irrigação com água salobra nos estágios fenológicos. Foi utilizado o delineamento inteiramente casualizado, com cinco tratamentos, correspondendo a cinco estratégias de irrigação (E1= água de menor salinidade (0,8 dS m^{-1}) durante todo o ciclo da cultura; E2= água de maior salinidade (3,0 dS m^{-1}) apenas nas fases de germinação e crescimento (0-11 DAS); E3= água de maior salinidade (3,0 dS m^{-1}) apenas na fase de pré-floração (12-22 DAS); E4= água de maior salinidade (3,0 dS m^{-1}) apenas na fase de frutificação (23-42 DAS); E5= água de maior salinidade (3,0 dS m^{-1}) apenas na fase de colheita (43-63 DAS), com oito repetições. A irrigação com água salobra (3,0 dS m^{-1}) durante as fases de pré-floração e frutificação afeta negativamente o comprimento e o diâmetro dos frutos de abobrinha italiana. A massa média dos frutos, a espessura da casca, a produção e a eficiência no uso da água são reduzidas quando irrigados com água de maior condutividade elétrica durante as fases de germinação e crescimento inicial, enquanto o teor de sólidos solúveis é aumentado. Em condições de alta salinidade é possível irrigar a cultura da abobrinha sem perda da qualidade e da produção dos frutos durante toda a fase de colheita.

Palavras-chave: *Cucurbita pepo*, salinidade, eficiência do uso da água, estágio fenológico

• Ref. 277139 – Received 30 Jul, 2023
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• Accepted 12 May, 2024 • Published 19 Jun, 2024
Editors: Lauriane Almeida dos Anjos Soares & Hans Raj Gheyi

Introduction

Zucchini (*Cucurbita pepo* L.), belonging to the Cucurbitaceae family, is characterized by its elongated and cylindrical shape. It is sensitive to low temperatures and thrives better in warm climates, such as that found in tropical or even semi-arid regions, with specific management practices (Filgueira, 2012; Guerra et al., 2020).

Adopting irrigation in the Italian zucchini crop ensures production reliability (Souza et al., 2020). However, in the Brazilian Northeast, production is severely affected due to the presence of brackish waters used in irrigation, containing high levels of toxic ions for crops such as Na^+ and Cl^- (Lessa et al., 2023a). Sousa et al. (2022a) observed that electrical conductivity of the water above 1 dS m^{-1} negatively affects the physiology and growth of the zucchini crop.

The consequences of exposure to high salt levels in irrigation water can lead plants to osmotic disturbance, significantly reducing water and nutrient uptake, and/or ionic imbalances caused by excess Na^+ and Cl^- (Lima et al., 2018; Sousa et al., 2021; Sousa et al., 2022b), resulting in morphophysiological and biochemical alterations, metabolic disorders (Souza et al., 2019; Sales et al., 2021), and consequently reducing the production potential of cultivated plants (Sousa et al., 2019).

In this context, studies exploring efficient irrigation management in saline and water-scarce environments, such as semi-arid regions, have been tested to minimize production impacts (Có et al., 2023; Lima et al., 2023). The cyclic use of brackish water at different phenological stages of the crop is an alternative, as plant tolerance may vary according to the phenological stage (Lacerda et al., 2021; Silva et al., 2022; Lessa et al., 2023b). Có et al. (2023) achieved greater water use efficiency in millet crop through the cyclic use of brackish water of 4 dS m^{-1}.

Given this scenario, the objective of the present study was to evaluate the production and fruit quality of Italian zucchini subjected to brackish water irrigation strategies at different phenological stages.

Material and Methods

The experiment was conducted under field conditions at the Unidade de Produção de Mudas das Auroras (UPMA), belonging to the Universidade da Integração Internacional da Lusofonia Afro-Brasileira (UNILAB) in Redenção, Ceará, Brazil (4° 13' 86 33" S; 38° 43' 39" W and altitude of 92 m) from June to August 2021. The climate of the region is classified as Aw, characterized as a rainy tropical climate, very hot, with predominant rainfall in the summer and autumn seasons (Alvares et al., 2013). The meteorological data obtained throughout the experimental period are presented in Figure 1.

For the experiment, a completely randomized design was used, with five treatments representing five irrigation strategies (S1 = use of low-salinity water (0.8 dS m^{-1}) throughout the crop cycle; S2 = use of high-salinity water (3.0 dS m^{-1}) only during germination and initial growth stages (0-11 DAS); S3 = use of high-salinity water (3.0 dS m^{-1}) only during pre-flowering stage (12-22 DAS); S4 = use of high-salinity water (3.0 dS m^{-1}) only during fruiting stage (23-42 DAS); S5 = use of high-salinity water (3.0 dS m^{-1}) only during harvesting stage (43-63 DAS); in the other stages, water with lower electrical conductivity (0.8 dS m^{-1}) was used, following the description by Delfim & Mauch (2017), with eight repetitions for each treatment.

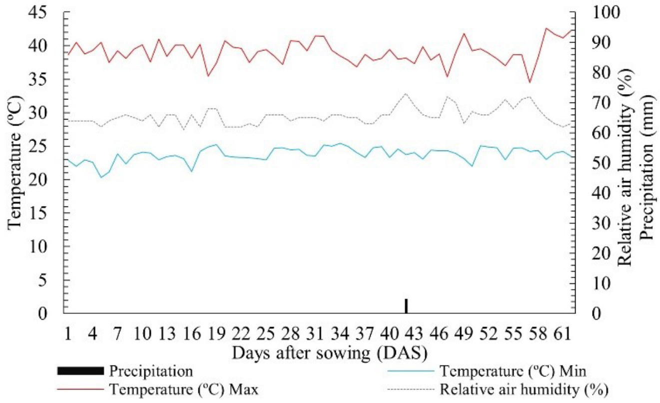


Figure 1. Mean values of maximum (Max) and minimum (Min) temperatures, precipitation, and relative air humidity observed during the experimental period (18 June to 20 August 2021)

Table 1 presents the distribution of irrigation strategies according to the established phenological stages, along with their respective electrical conductivity levels.

Seeds of Italian zucchini, cv. Caserta, were used, five per pot, and each pot had a volumetric capacity of 11 dm^3. At 10 days after sowing (DAS), thinning was performed, leaving one plant per pot. The pots were filled with a substrate formulated from a mixture of arisco (sandy material with light texture normally used in constructions in Northeast Brazil), sand, and bovine manure in a ratio of 4:2:1 (volume basis), respectively. A representative sample of the substrate was collected and sent to the Soil and Water Laboratory of the Universidade Federal do Ceará (UFC) for chemical characterization (Table 2), following the methodology of Teixeira et al. (2017).

The water of 3.0 dS m^{-1} was prepared based on Sousa et al. (2022a) by dissolving NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ salts in the supply water of the experimental area, corresponding to the lowest salinity treatment (0.8 dS m^{-1}), in an equivalent proportion of 7:2:1, respectively, following the relationship between ECw and the concentration ($mmol_c\ L^{-1} \approx EC \times 10$), as described in Richards (1954). Irrigation was performed manually, with daily frequency, using the water balance, calculated according to the principle of the drainage lysimeter,

Table 1. Irrigation strategies in Italian zucchini crop during phenological stages

Strategies	Phenological stages (days after sowing - DAS)			
	Germination 0-11	Pre-flowering 12-22	Fruiting 23-42	Harvesting 43-63
S1	W1	W1	W1	W1
S2	W2	W1	W1	W1
S3	W1	W2	W1	W1
S4	W1	W1	W2	W1
S5	W1	W1	W1	W2

W1- 0.8 dS m^{-1} and W2- 3.0 dS m^{-1}. S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS)

Table 2. Chemical characteristics of the substrate before the beginning of the treatments

OM	N	P	Ca^{2+}	K^+	Mg^{2+}	Na^+	$H^+ + Al^{3+}$	SB	CEC	V	ESP	ECse	pH
($g\ kg^{-1}$)		($mg\ kg^{-1}$)	($cmol_c\ kg^{-1}$)							(%)		($dS\ m^{-1}$)	(H_2O)
17.0	3.0	5.9	5.0	0.1	1.0	0.08	0.7	6.1	6.9	89	1.1	2.0	5.4

OM - Organic matter; SB - Sum of bases ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$); CEC - Cation exchange capacity - [$Ca^{2+} + Mg^{2+} + Na^+ + K^+ + (H^+ + Al^{3+})$]; V - Base saturation - ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$/ CEC) × 100; ESP - Exchangeable sodium percentage; ECse - Electrical conductivity of the saturation extract of the substrate

by adapting the pots (11 dm^3) as a micro-lysimeter, to keep the soil at field capacity, following Eq. 1. A leaching depth of 15% was considered for each irrigation event to avoid excessive accumulation of salts, according to Ayers & Westcot (1999).

$$VI = \frac{(Vp - Vd)}{(1 - LF)} \quad (1)$$

where:

VI - volume of water to be applied in the irrigation event (mL);

Vp - volume of water applied in the previous irrigation event (mL);

Vd - volume of water drained (mL) after last event; and,

LF - leaching fraction of 0.15.

The volume of the water applied per treatment and the total during the experiment are presented in Table 3.

For crop maintenance, mineral fertilization was carried out following recommendations of Filgueira (2012), corresponding to 140 kg ha^{-1} of N, 300 kg ha^{-1} of P_2O_5, and 150 kg ha^{-1} of K_2O, using urea (45% N), triple superphosphate (46% P_2O_5), and potassium chloride (60% K_2O), respectively. Fertilizer was applied as basal and as topdressing (15 and 25 DAS). Simulating a stand of 10,000 plants ha^{-1}, each pot per plant per cycle received 14 g of N, 30 g of P_2O_5, and 15 g of K_2O.

Manual weeding was performed as needed based on the appearance of weeds in the pots, and no applications of pest and disease control inputs were required. In addition, plants were staked at the base of the pot to prevent tipping and mechanical damage to the fruit.

Between the periods of 50 to 63 DAS (harvesting stage), the fruits were harvested when fully formed with the characteristic color of the cultivar (light green skin and dark green stripes) and appeared shiny, tender and fiberless, indicative of the harvesting stage. The following variables were measured: number of fruits per plant (NFP) through direct counting of harvested fruits per plant; fruit length (FL, cm) measured longitudinally using a graduated ruler; fruit diameter (FD, mm) measured at the transverse base with a caliper; skin (rind) thickness (ST, mm) measured with a caliper after transversely cutting the fruits; average fruit mass (AFM, g) obtained from the total fresh weight measured on a precision scale and number of fruits harvested for each plant; content of soluble solids (SS, °Brix) analyzed in the pulp after processing, with an analog refractometer; production (PRO, g per plant), measured on a semi-analytical precision scale; and water use efficiency (WUE, g L^{-1}) obtained from the ratio between fresh fruit weight and the volume of water applied in irrigation.

Table 3. Volume of the water applied per treatment and total

Strategies	Phenological stages (days after sowing - DAS)				Total
	Germination 0-11	Pre-flowering 12-22	Flowering 23-42	Harvesting 43-63	
	Volume of the water applied (L)				
S1	10.05	9.50	17.10	12.50	49.15
S2	10.05	9.50	17.10	12.50	
S3	10.05	9.50	17.10	12.50	
S4	10.05	9.50	17.10	12.50	
S5	10.05	9.50	17.10	12.50	

S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS)

The data were subjected to the Kolmogorov-Smirnov test ($p \leq 0.05$) to assess normality. After verifying normality, the data were subjected to analysis of variance, using the F test, and when significant, they were subjected to the Tukey test at 0.01 and 0.05 probability levels using the software Assistat 7.7 Beta (Silva & Azevedo, 2016).

Results and Discussion

According to the analysis of variance the variable number of fruits per plant (NFP) was not influenced by the strategies used. However, the other analyzed variables were significantly influenced by the irrigation strategies factor, with fruit diameter (FD) and skin (rind) thickness (ST) at $p \leq 0.01$. The effects on fruit length (FL), average fruit mass (AFM), soluble solids (SS), production (PRO), and water use efficiency (WUE) were significant at $p \leq 0.05$ (Table 4).

Fruit diameter was higher in S1 (use of water with low electrical conductivity throughout the cycle). On the other hand, the application of S3 and S4 strategies resulted in the smallest diameters (18.58 and 20.10 mm, respectively), showing significant differences from the strategy without salt stress (Figure 2). This fact is directly related to the deleterious effects of salts on fruit formation, triggered by the salt effect that reduces the osmotic potential, impairing water absorption, as well as disrupting photoassimilate production, inhibiting cell expansion due to the use of brackish water during the pre-flowering and fruiting stages (Lima et al., 2020). This reduction in fruit diameter demonstrates the sensitivity of the crop during these stages. Reduction in the transverse diameter in Italian zucchini was reported by Souza et al. (2020) when using highly saline water (5.0 dS m^{-1}) for irrigation throughout the crop cycle.

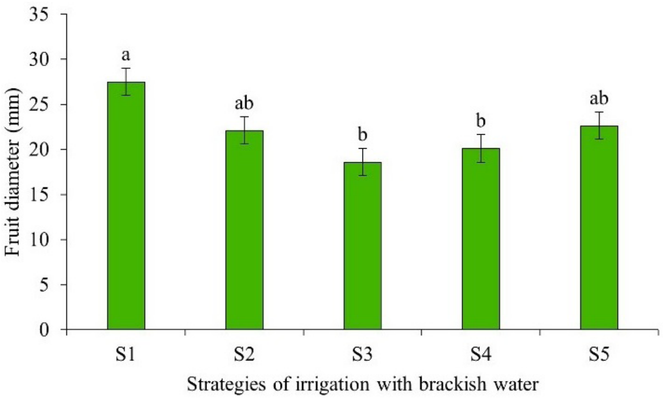
According to Figure 3, a significant reduction was observed in the length of Italian zucchini fruits when subjected to salt stress during the fruiting stage (S4= 7.43 cm) compared to the highest mean obtained in S2, 9.72 cm (use of water with high salinity (3.0 dS m^{-1}) only during germination and initial growth stages), with a reduction of about 23.55%.

This reduction under salt stress during the fruiting stage can be considered an acclimation alternative to minimize the uptake of saline water, especially containing Na^+ and Cl^- ions.

Table 4. Summary of the analysis of variance for the variables number of fruits per plant (NFP), fruit diameter (FD), fruit length (FL), skin (rind) thickness (ST), average fruit mass (AFM), soluble solids (SS), production (PRO), and water use efficiency (WUE) of Italian zucchini crop under brackish water irrigation strategies at different phenological stages

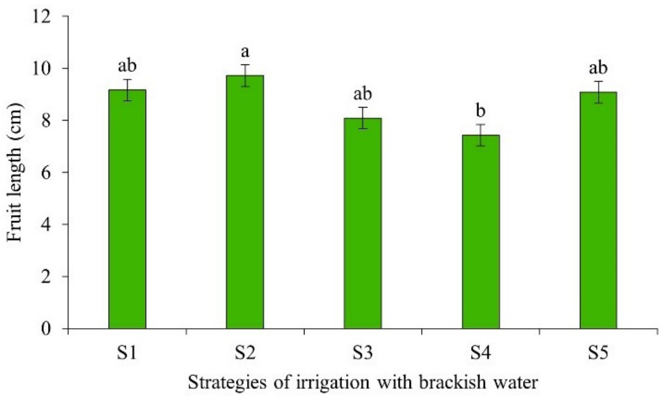
SV	DF	Mean squares							
		NFP	FD	FL	ST	AFM	SS	PRO	WUE
Strategies (S)	4	3.46^{ns}	91.08**	6.82*	0.35**	2327.12*	2.96*	942120.75*	1.89*
Residual	35	3.40	17.81	1.86	0.06	748.65	0.93	303086.09	0.61
Total	39	-	-	-	-	-	-	-	-
CV (%)	-	22.43	19.04	15.70	23.00	26.63	19.62	25.74	26.63

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



S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

Figure 2. Fruit diameter of Italian zucchini under different strategies of irrigation with brackish water



S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

Figure 3. Fruit length of Italian zucchini under different strategies of irrigation with brackish water

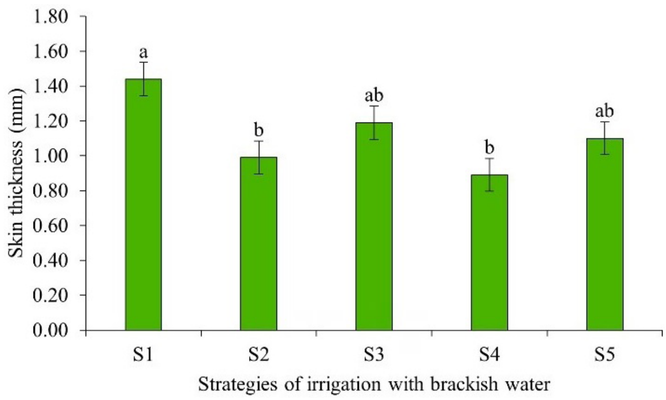
High salinity levels lead to low osmotic potential, reduction in relative water content, and diminished nutrient absorption, ultimately affecting production aspects (Lima et al., 2020; Souza et al., 2020), such as fruit size.

When evaluating watermelon crop under different strategies of irrigation with saline water (4.0 dS m^{-1}), Silva et al. (2022) reported a similar reduction in fruit equatorial diameter as in the present study, when salt stress was applied during the fruiting stage. However, Souza et al. (2020) did not observe a significant reduction in zucchini length under salt stress (0.5 and 5.0 dS m^{-1}) throughout the entire cycle.

Zucchini fruit skin thickness was higher without salt stress throughout the entire cycle (S1= 1.44 mm). Under irrigation treatments S2 and S4, the thickness (0.99 and 0.89 mm, respectively) was significantly reduced compared to the S1, demonstrating the sensitivity of the crop during the germination, growth, and fruiting stages (Figure 4).

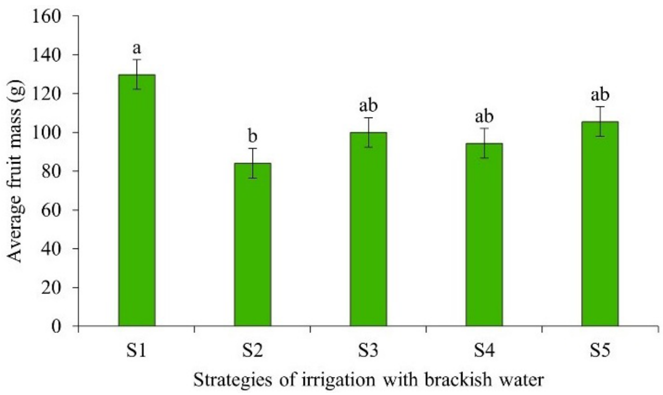
Similarly to the data presented in this study, Dantas et al. (2018) found that salt stress negatively affected the fruit rind thickness in melon crop, a characteristic that can impact fruit quality and shelf life by reducing resistance to transportation and storage. Considering that high salinity can induce disorders such as water deficit and nutrient imbalance, the decrease in rind thickness induced by salinity may be partially explained by these disorders, as observed by Gomes do Ó et al. (2021). When evaluating 'Crimson Sweet' watermelon under brackish water irrigation, these authors reported that high salinity resulted in a linear decrease of 8.86% in rind thickness per unit increase in salinity. Specifically, the increase in salinity resulted in a 45% reduction in rind thickness in the 6.5 dS m^{-1} treatment (1.5 cm) compared to the control treatment (2.7 cm).

It can be observed in Figure 5 that the lowest average fruit mass (84.11 g) was obtained in S2, which used water with higher salinity (3.0 dS m^{-1}) during the germination and initial growth stages (0-11 DAS), significantly different from S1, with the highest averages (129.75 g; water with lower salinity (0.8 dS m^{-1}) throughout the growing cycle), while S3, S4, and S5



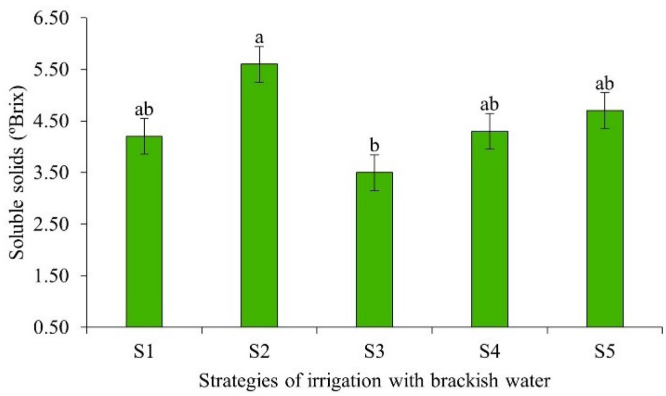
S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

Figure 4. Skin (rind) thickness of Italian zucchini under different strategies of irrigation with brackish water



S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

Figure 5. Average fruit mass of Italian zucchini under different strategies of irrigation with brackish water



S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

Figure 6. Soluble solids content of Italian zucchini under different strategies of irrigation with brackish water

(99.95, 94.26, and 105.54 g, respectively) were not statistically different from the others.

The increase in soil salt content, resulting from progressive deposition of salt through irrigation water, leads to a reduction in availability of NPK and Ca levels, which are important for fruit mass performance (Lima et al., 2018; Sousa et al., 2022b). This reduction is directly related to salinity stress, which immediately reduces soil water potential, making the soil solution unavailable or not readily available for nutrient uptake by plants (Lima et al., 2023; Sousa et al., 2022b).

When evaluating the production and post-harvest quality of mini watermelon under strategies of irrigation with high-salt content water, Silva et al. (2022) observed contrasting results to those obtained in this study, where the strategy with saline water application during the vegetative stage did not differ statistically from the strategy with low salinity application throughout the entire cycle.

The content of soluble solids was higher with irrigation using saline water (3.0 dS m^{-1}) only during the germination and initial growth stages (S2), being about 37.5% higher when compared to the lowest value obtained in S3 (salt stress during the pre-flowering stage) (Figure 6).

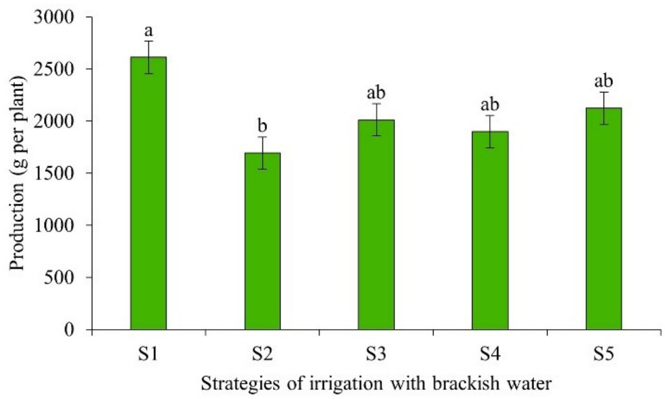
This increase is explained by the reduction in water absorption caused by the excess of salts, decreasing the internal content, generating a higher solute concentration per fruit, and consequently increasing the soluble solids (Gadelha et al., 2021; Silva et al., 2022). Further supporting this, the results obtained for average fruit mass (Figure 5) were significantly reduced at stage S2, resulting in smaller fruits but with higher soluble solids concentration.

When evaluating the fruit quality of watermelon under strategies of irrigation with brackish water (4.0 dS m^{-1}), Silva et al. (2022) reported that applying salt stress during the vegetative and flowering stages of the crop did not increase the soluble solids content in the fruits.

The production of zucchini crop was statistically higher in the treatment using low-salinity water throughout the cycle (S1). However, when salt stress was applied during the germination and initial growth stages (S2), it significantly reduced the production by about 37.5%, but this treatment did not differ statistically from the other strategies with brackish water (Figure 7).

This drastic reduction demonstrates that the crop shows greater sensitivity in the initial stage. The tolerance and/or sensitivity levels of crops to salt stress can vary between development stages, but in general, most crops are more sensitive to salinity during the initial phenological stages (Araújo et al., 2016). This fact is directly linked to the reduction in water absorption due to the decrease in soil osmotic potential, as well as injuries related to the absorption of large amounts of toxic ions (Na^+ and Cl^-), damaging the photosynthetic apparatus due to metabolic and biochemical alterations, directly affecting the production and distribution of assimilates throughout the phenological cycle of the crop (Sales et al., 2021; Lima et al., 2023).

When evaluating the zucchini crop under salt stress (irrigating with 5.0 dS m^{-1} water) throughout the cycle, Souza et al. (2020) observed a 57.31% reduction in production compared to irrigation with lower electrical conductivity water



S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

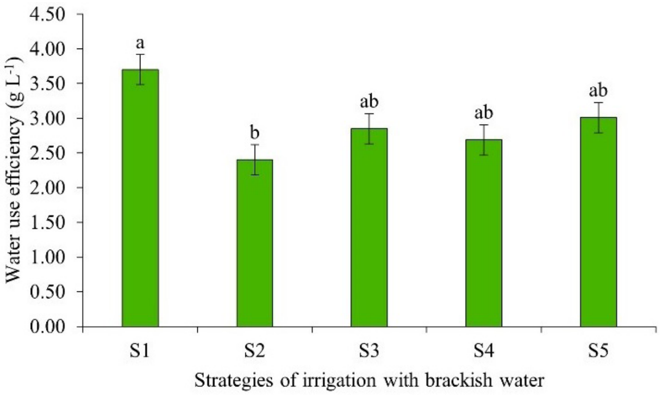
Figure 7. Production of Italian zucchini under different strategies of irrigation with brackish water

(EC= 0.5 dS m^{-1}). On the other hand, Gadelha et al. (2021) reported that beet crop reduced its yield under conditions of high irrigation water salinity (5.8 dS m^{-1}) from the initial growth stage.

The water use efficiency responded similarly to production. The lowest WUE (2.40 g L^{-1}) was obtained in S2 (saline water during germination and initial growth stages), statistically differing only from S1 (3.70 g L^{-1}), the strategy in which low-salinity water was used throughout the crop cycle (Figure 8).

It is observed that, regardless of the stage in which higher salinity water was used for irrigation, there was a negative response in terms of reduction in WUE compared to the strategy in which low-salinity water was used in entire cycle. However, the reduction was more severe in the initial stages. This result demonstrates the deleterious effects of salinity regardless of the application period, which are possibly related to the reduction in osmotic potential, consequently causing the plant to absorb less water due to the low suction pressure to overcome osmotic pressure (Gomes do Ó et al., 2021), reducing the ability of the crop to effectively use available water.

In the light of the results, it is possible to identify pathways for the Italian zucchini crop under biosaline conditions. The cyclic use of brackish water according to the phenological stage emerges as a viable alternative, aiming to understand the tolerance level at each stage. The results of this study show that irrigation with water with relatively high salinity, regardless of the phenological stage, had negative effects on the cv. Caserta. This is confirmed by similar effects in reducing water use efficiency and fruit production. However, it is also possible to identify more tolerant stages without significant yield losses. Therefore, it is crucial to identify stages of greater tolerance for crops under salinity stress in order to seek less drastic reductions and higher financial returns under adverse conditions of elevated salinity.



S1- Water with low salinity (0.8 dS m^{-1}) throughout the crop cycle; S2- Water with high salinity (3.0 dS m^{-1}) only in the germination and initial growth stages (0-11 DAS); S3- Water with high salinity (3.0 dS m^{-1}) only in the pre-flowering stage (12-22 DAS); S4- Water with high salinity (3.0 dS m^{-1}) only in the fruiting stage (23-42 DAS); S5- Water with high salinity (3.0 dS m^{-1}) only during the harvest stage (43-63 DAS). Means followed by different lowercase letters indicate significant differences by Tukey test ($p \leq 0.05$). Vertical bars represent the standard error of mean (n = 8)

Figure 8. Water use efficiency of Italian zucchini under different strategies of irrigation with brackish water

Conclusions

1. Irrigation with brackish water (EC= 3.0 dS m^{-1}) during the pre-flowering and fruiting stages negatively affects the length and diameter of Italian zucchini fruits.

2. The average fruit mass, skin (rind) thickness, production, and water use efficiency of Italian zucchini fruits are reduced when irrigated with water of higher electrical conductivity (3.0 dS m^{-1}) during the germination and initial growth stages, while the soluble solids content is increased.

3. Under conditions of high salinity, it is possible to irrigate zucchini crop without loss of fruit quality and production throughout the harvesting stage.

Contribution of authors: Tamires da C. M. Semedo worked on preparing the first version of the manuscript, literature review, research, data acquisition, and data analysis. Geocleber G. de Sousa acted as a research advisor and worked on the conceptualization of the problem, improvements, and corrections to the manuscript. Henderson C. Sousa worked on research, data acquisition, data analysis, and writing - review & editing. Fernanda Schneider contributed in the review and final version of the manuscript. José M. dos P. Lima worked preparing the first version of the manuscript and conducting a literature review. Krishna R. Gomes worked on data analysis, improvements, and corrections to the manuscript. Antonio Á. F. Simplício contributed in the review and final version of the manuscript. Kleiton R. Saraiva worked on data analysis, improvements, and corrections to the manuscript.

Supplementary documents: There are no supplementary sources.

Conflict of interest: The authors declare no conflict of interest.

Financing statement: There are no financing statements to declare.

Literature Cited

Ayers, R. S.; Westcot, D. W. A qualidade da água na agricultura. 2.ed. Campina Grande: UFPB, 1999. 153p. Estudos FAO: Irrigação e Drenagem, 29

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. de M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Araújo, E. B. G.; Sá, F. V. da S.; Oliveira, F. A. de; Souto, L. S.; Paiva, E. P. de; Silva, K. do N.; Mesquita, E. F. de; Brito, M. E. B. Crescimento inicial e tolerância de cultivares de meloeiro à salinidade da água. Revista Ambiente Água, v.11, p.462-470, 2016. https://dx.doi.org/10.4136/ambi-agua.1726

Có, E. G. de; Sousa, G. G. de; Gomes, S. P.; Freire, M. H. da C.; Silva, F. D. B. da. Strategies for the management of irrigation with saline water and nitrogen fertilization in millet crop. Revista Caatinga, v.36, p.424-431, 2023. http://dx.doi.org/10.1590/1983-21252023v36n219rc

Dantas, E. P.; Queiroga, R. C. F. de; Silva, Z. L. da; Assis, L. E. de; Sousa, F. F. de. Yield and quality of the muskmelon under the seed osmoconditioning and water salinity levels. Revista Verde de Agroecologia e Desenvolvimento Sustentável, v.13, p.8-15, 2018. http://dx.doi.org/10.18378/rvads.v13i1.5013

Delfim, T. F.; Mauch, C. R. Fenologia, qualidade e produtividade de frutos de genótipos de abobrinha cultivados em ambiente protegido. Tecnologia e Ciência Agropecuária, v.11, p.49-55, 2017.

Filgueira, F. A. R. Novo manual de olericultura: Agrotecnologia moderna na produção e comercialização de hortaliças. 3.ed. Viçosa: Editora UFV, 2012. 421p.

Gadelha, B. B.; Freire, M. H. da C.; Sousa, H. C. Costa, F. H. R.; Lessa, C. I. N.; Sousa, G. G. de. Growth and yield of beet irrigated with saline water in different types of vegetable mulching. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.847-852, 2021. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n12p847-852

Gomes do Ó, L. M.; Cova, A. M. W.; Azevedo Neto, A. D. de; Souza, M. G.; Santos, A. L.; Gheyi, H. R. Production, water-use efficiency and post-harvest quality of hydroponic mini watermelon under salinity stress. Pesquisa Agropecuária Tropical, v.51, e67054, 2021. https://doi.org/10.1590/1983-40632021v5167054

Guerra, A. M. de M.; Silva, M. G. M.; Evangelista, R. S.; Santos, E. B. dos; Nogueira, W. P. Produção de cultivares de abobrinha italiana a pleno sol e sombreada no Nordeste brasileiro. Agropecuária Técnica, v.41, p.1-7, 2020. https://doi.org/10.25066/agrotec.v41i1-2.50535

Lacerda, C. F.; Gheyi, R. H.; Medeiros, J. F.; Costa, R. N. T.; Sousa, G. G.; Lima, G. S. Strategies for the use of brackish water for crop production in northeastern Brazil. In: Taleisnik, E.; Lavado, R.S. Saline and alkaline soils in Latin America: Natural resources, management and productive alternatives. Nova York: Springer, 2021. p.71-99.

Lessa, C. I. N.; Lacerda, C. F. de; Cajazeiras, C. C. de A.; Neves, A. L. R.; Lopes, F. B.; Silva, A. O. da; Sousa, H. C.; Gheyi, H. R.; Nogueira, R. da S.; Lima, S. C. R. V.; Costa, R. N. T.; Sousa, G. G. de. Potential of brackish groundwater for different biosaline agriculture systems in the Brazilian semi-arid region. Agriculture, v.13, e550, 2023a. https://doi.org/10.3390/agriculture13030550

Lessa, C. I. N.; Sousa. G. G. de; Sousa, H. C.; Lacerda, C. F. de; Silva, A. O.; Guilherme, J. M. da S. Morphophysiology of passion-fruit seedlings in different substrates under different strategies of irrigation with brackish water. Revista Ambiente & Água, v.18, p.1-14, 2023b. https://doi.org/10.4136/ambi-agua.2907

Lima, G. S.; Silva, A. A. R. da; Torres, R. A. F.; Soares, L. A. dos A.; Gheyi, H. R.; Silva, F. A. da; Nobre, R. G.; Azevedo, C. A. V. de; Lopes, K. P.; Chaves, L. H. G.; Lima, V. L. A. de. NPK accumulation, physiology, and production of sour passion fruit under salt stress irrigated with brackish water in the phenological stages and K fertilization. Plants, v.12, e1573, 2023. https://doi.org/10.3390/plants12071573

Lima, G. S.; Fernandes, C. G. J.; Soares, L. A. A.; Gheyi, H. R.; Fernandes, P. D. Gas exchange, chloroplast pigments and growth of passion fruit cultivated with saline water and potassium fertilization. Revista Caatinga, v.33, p.184-194, 2020. https://doi.org/10.1590/1983-21252020v33n120rc

Lima, G. S. de; Dias, A. S.; Gheyi, H. R.; Soares, L. A. dos A.; Andrade, E. M. G. Saline water irrigation and nitrogen fertilization on the cultivation of colored fiber cotton. Revista Caatinga, v.31, p.151-160, 2018. https://doi.org/10.1590/1983-21252018v31n118rc

Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington: US Department of Agriculture, 1954. 160p. USDA Agricultural Handbook, 60

Sales, J. R. da S.; Magalhaes, C. L.; Freitas, A. G. S.; Goes, G. F.; Sousa, H. C.; Sousa, G. G. de. Physiological indices of okra under organomineral fertilization and irrigated with salt water. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.466-471, 2021. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n1p3-9

Silva, F. A. S.; Azevedo, C. A. V. The Assistat software version 7.7 and its use in the analysis of experimental data. African Journal of Agricultural Research, v.11, p.3733-3740, 2016. https://doi.org/10.5897/AJAR2016.11522

Silva, S. S. da; Lima, G. S. de; Lima, V. L. A. de; Gheyi, H. R.; Soares, L. A. dos A.; Oliveira, J. P. M. Production and post-harvest quality of mini-watermelon crop under irrigation management strategies and potassium fertilization. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.51-58, 2022. http://dx.doi.org/10.1590/1807-1929/agriambi.v26n1p51-58

Sousa, G. G. de; Sousa, H. C.; Santos, M. F. dos; Lessa, C. I. N.; Gomes, S. P. Saline water and nitrogen fertilization on leaf composition and yield of corn. Revista Caatinga, v.35, p.191-198, 2022b. http://dx.doi.org/10.1590/1983-21252022v35n119rc

Sousa, H. C.; Sousa, G. G. de; Cambissa, P. B. C.; Lessa, C. I.; Goes, G. F.; Silva, F. D. B. da; Abreu, F. da S.; Viana, T. V. de A. Gas exchange and growth of zucchini crop subjected to salt and water stress. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.815-822, 2022a. https://doi.org/10.1590/1807-1929/agriambi.v26n11p815-822

Sousa, H. C.; Sousa, G. G. de; Lessa, C. I. N.; Lima, A. F. da S.; Ribeiro, R. M. R.; Rodrigues, F. H. da C. Growth and gas exchange of corn under salt stress and nitrogen doses. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.174-181, 2021. https://doi.org/10.1590/1807-1929/agriambi.v25n3p174-181

Sousa, V. F. de O.; Costa, C. C.; Diniz, G. L.; Santos, J. B. dos; Bonfim, M. P.; Lopes, K. P. Growth and gas changes of melon seedlings submitted to water salinity. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.90-96, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n2p90-96

Souza, M. V. P. de; Sousa, G. G. de; Sales, J. R. da S.; Freire, M. H. da C.; Silva, G. L. da; Viana, T. V. de A. Saline water and biofertilizer from bovine and goat manure in the lima bean crop. Revista Brasileira de Ciências Agrárias. v.14, p.1-8, 2019. http://dx.doi.org/10.5039/agraria.v14i3a5672

Souza, M. W. de L.; Torres, S. B.; Oliveira, F. de A.; Marques, I. C. da S.; Pereira, K. T. O.; Guimarães, I. T. Saline-water irrigation and plant growth regulator application on zucchini fruit yield and quality. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.679-684, 2020. http://dx.doi.org/10.1590/1807-1929/agriambi.v24n10p679-684

Teixeira, P. C.; Donagemma, G. K.; Fontana, A.; Teixeira W. G. Manual de métodos de análise de solo. 3.ed. Brasília: Embrapa, 2017. 573p.