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CRESCIMENTO, PRODUÇÃO E TOLERÂNCIA DO BROCÓLIS EM HIDROPONIA COM O USO DE ÁGUAS SALOBRAS

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1 RESUMO

O presente estudo foi realizado visando avaliar o cultivo de brócolis (*Brassica oleracea* var. *itálica*, cv. 'Imperial') empregando águas salobras em sistema hidropônico. Dois experimentos foram realizados simultaneamente em casa de vegetação sob hidroponia NFT, entre março e junho de 2022 (outono-inverno): um com reposição com água doce e outro com águas salobras. As plantas foram submetidas a quatro níveis de condutividade elétrica (CE) da água: 0,3 dS m^{-1} (controle, sem adição de NaCl), 1,75, 3,50 e 5,25 dS m^{-1} (com adição de NaCl), no delineamento em blocos casualizados com seis repetições. Ao longo dos experimentos, foram realizadas medições biométricas e, no ponto de colheita, avaliou-se o crescimento vegetativo, a biometria e produção das inflorescências, além de sua qualidade. Também foi calculado o teor de água nas folhas e inflorescências. Os resultados indicam que é viável cultivar o brócolis com CE da solução nutritiva de até 4,46 dS m^{-1} no outono-inverno. Contudo, no experimento com águas salobras, foram observadas perdas na qualidade comercial no nível salino mais alto. Portanto, recomenda-se evitar o uso exclusivo de águas salobras com CE de 5,25 dS m^{-1}, reservando-as apenas para o preparo das soluções nutritivas.

Palavras-chave: *Brassica oleracea*, água de baixa qualidade, inflorescência, hidroponia NFT, estresse salino.

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2 ABSTRACT

The present study aimed to evaluate the cultivation of broccoli (*Brassica oleracea* var. *itálica*, cv. 'Imperial') using brackish water in a hydroponic system. Two experiments were simultaneously conducted in a greenhouse under NFT hydroponics between March and June 2022 (autumn-winter): one with replenishment using fresh water and the other with brackish water. The plants were subjected to four levels of electrical conductivity (EC) of the water: 0.3

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dS m⁻¹ (control, no NaCl added), 1.75, 3.50, and 5.25 dS m⁻¹ (with NaCl addition), in a randomized block design with six replications. Throughout the experiments, biometric measurements were taken, and at harvest time, vegetative growth, biometric parameters, inflorescence production, and quality were evaluated. The water content of the leaves and inflorescences was also calculated. The results indicate that broccoli can be cultivated with an EC of up to 4.46 dS m⁻¹ in nutrient solution during autumn–winter. However, in the experiment with brackish water, losses in commercial quality were observed at the highest salinity level. Therefore, it is recommended to avoid the exclusive use of brackish water with an EC of 5.25 dS m⁻¹, which should be reserved only for nutrient solution preparation.

Keywords: *Brassica oleracea*, poor water quality, inflorescence, NFT hydroponics, salt stress.

3 INTRODUCTION

How to use water resources sustainably to ensure food security is a major challenge for present and future generations (Wang *et al*., 2022). Freshwater scarcity due to climate change is one of the most important challenges for agricultural production (Gorfie *et al*., 2022). Therefore, it is important to use unconventional water resources for irrigation to alleviate the pressure of insufficient freshwater resources.

In recent years, research on the utilization of brackish water has focused on aspects such as salinity, soil texture, suitable crops and field management, resulting in the formation of a relatively complete technical system (Liu *et al*., 2021).

In arid and semiarid regions, the scarcity of low-salinity water has led to the use of brackish water for irrigation (Mengjie *et al*., 2021; Silva *et al*., 2018; Chehab *et al*., 2020; Khaleghi *et al*., 2020). However, this use can increase the risk of soil salinization and reduce crop productivity (Ellouzi *et al*., 2021; Sharma *et al*., 2020).

To mitigate salinity problems when brackish water is used for irrigation, several strategies have been adopted, highlighting the transition from conventional soil cultivation systems to hydroponic systems (Atzori; Mancuso; Masi, 2019; Bione *et al*., 2021; Silva *et al*., 2022), mainly for vegetable cultivation (Silva *et al*., 2018; Alves *et al*., 2019).

Hydroponics can increase plant tolerance to salinity, since it eliminates the water/air interface between solid soil particles (there is no retention energy through the matric potential), thus resulting only from osmotic stress (Atzori *et al*., 2019; Freitas *et al*., 2019; Silva *et al*., 2020a; Silva *et al*., 2020b).

Furthermore, hydroponics results in an earlier harvest than does soil cultivation, favoring the response of plants to salinity. This technique has been applied to short-cycle vegetables, such as Chinese cabbage (Lira *et al*., 2015), coriander (Silva *et al*., 2016, Silva *et al*., 2016, Silva *et al*., Silva *et al*., *Silva et al*., 2020b), arugula (Campos Júnior *et al*., 2018; Silva *et al*., 2022), watercress (Lira *et al*., 2018; Souza *et al*., 2020), chicory (Alves *et al*., 2019; Silva *et al*., 2020a), parsley (Martins *et al*., 2020), chives (Silva Júnior *et al*., 2019), lettuce (Soares *et al*., 2019; Freitas *et al*., 2021; Silva *et al*., 2021a), but it also allows the cultivation of species with longer cycles, such as peppers (Santos *et al*., 2018), okra (Modesto *et al*., 2019), cauliflower (Costa *et al*., 2020; Soares *et al*., 2020; Santos *et al*., 2021), melon (Ulas *et al*., 2021a), and pepper (Batista *et al*., 2021).

The vegetable broccoli (*Brassica oleracea* var. *italica*), a crop that is moderately sensitive to salinity, is widely cultivated in regions with mild climates. Its nutritional value and nutraceutical properties make it stand out among vegetables, with its inflorescence being the most consumed part of the plant (Lalla *et al*., 2010). In Brazil, its cultivation is concentrated in the Central-South region, especially in the Federal District, Rio Grande do Sul, Paraná and São Paulo, where it is sold fresh or processed (Cecílio Filho; Schiavon Júnior; Cortez, 2012).

Previous studies indicate that broccoli is classified as a moderately salinity-sensitive crop, which can result in a 9.2% reduction in yield for each unit increase in soil saturation, resulting in an electrical conductivity above 2.8 dS m^{-1} (Maas; Hoffman, 1977; Maas, 1984). However, these data were obtained from soil cultivation, and studies on broccoli production in hydroponics with brackish water are lacking. Although kale and cauliflower have been investigated under these conditions, there is still a gap in the exploration of broccoli.

The visual appearance of products is crucial for consumer acceptance, and saline stress can, in some cases, even improve product quality (Bonasia *et al*., 2017; D'Imperio *et al*., 2018). Giuffrida *et al*. (2018), for example, reported that the application of moderate saline stress improved the organoleptic properties of cauliflower inflorescences in soilless cultivation, thus increasing the shelf-life of the product.

Given the above, this study was conducted with the aim of evaluating the effects of using brackish water, under hydroponic conditions, on the growth, production, quality and tolerance of broccoli to salinity.

4 MATERIALS AND METHODS

4.1 Location of the study area

Two concomitant experiments were carried out with broccoli (*Brassica oleracea* var. *italica*) in a greenhouse between April and June 2022 (autumn-winter). The experimental site facilities are part of the experimental area of the Postgraduate Program in Agricultural Engineering at the Center for Water and Soil Engineering (NEAS) of the Federal University of Recôncavo da Bahia (UFRB), Cruz das Almas-BA (12° 40' 19” South latitude, 39° 06' 23” West longitude and altitude of 220 m), Brazil.

4.2 Experimental design and treatments

In both experiments, broccoli plants were subjected to four levels of water electrical conductivity (ECa): 0.3 – control (without NaCl); 1.75; 3.50 and 5.25 dS m^{-1} (with NaCl), in a randomized block design with six replications. NaCl concentrations of 0.00, 1.03, 2.01 and 2.99 g/L were used to obtain saline samples, which were prepared in a low-salinity water supply (ECa 0.3 dS/m).

Two replacement strategies were adopted: in one of the experiments, brackish water was used only to prepare the nutrient solutions, while the water consumed by the plants was replenished with water from the supply for all the treatments. In the other experiment, brackish water was used both to prepare the solutions and to replenish the plants for water consumption.

4.3 Experimental structure

Broccoli plants were grown in the NFT hydroponic system (laminar flow nutrient technique) in 0.075 m diameter PVC hydroponic channels that were 6 m long. The channels were arranged on benches with a 5.0% slope and were built with 0.05 m diameter PVC pipe stands, with two channels per bench, resulting in spacings of 0.56 m × 0.80 m between the plants and channels.

Plastic tanks with a capacity of 500 L were used to store the nutrient mixture, with ball valves at the bottom of the tank and outlets for the pumps built with 0.015 m diameter PVC pipes. A 32 W electric pump was used to inject the solution into the six hydroponic channels simultaneously. After being pumped into the channel, the excess solution returned to the reservoir by gravity. Each reservoir was equipped with a float valve, which maintained the solution volume constant at 400 L, through a water replenishment tank responsible for replacing the water consumed by the plants, as described by Costa *et al*. (2020) and Silva *et al*. (2020c).

The control of the electric pumps was carried out with an analog timer programmed to change the circulations in 15-minute intervals (15 minutes working and 15 minutes at rest) from 6:00 a.m. to 6:00 p.m. During the night period, the nutrient solutions were circulated every 2 hours, with a duration of 15 minutes for each event.

4.4 Seedling production and plant management in the hydroponic system

The sowing of 'Imperial' broccoli (Sakata ® Sementes, São Paulo, Brazil) took place on March 30, 2022. The seeds were sown in phenolic foam (2 × 2 × 2 cm), one per cell. Germination occurred 2 days after sowing (DAS). The seedlings were then taken to a nursery built with PVC tiles (NFT system), where they received a nutrient solution according to Furlani *et al*. (1999) at 50% (electrical conductivity of the solution – CEsol ~ 1.0 dS m^{-1}) for periods of 23 days.

At 30 DAS, broccoli seedlings were transplanted into hydroponic channels, with a total of six seedlings per channel, spaced 0.7 m between rows and 0.5 m between plants. During the experiment, obstructions in the hydroponic channels occurred because of the robust root system of broccoli. Therefore, it is recommended to use channels with a diameter greater than 0.075 m for growing broccoli in NFT hydroponic profiles. Figure 1 presents an overview of the experiment.

Figure 1. Overview of the broccoli cultivation experiment in an NFT hydroponic system

Source: Authors (2024).

4.5 Monitoring the nutrient solution

In the definitive cultivation system, the plants received a nutrient solution according to Furlani *et al*. (1999) at a concentration of 100%, prepared with water of different salinities (with NaCl), as shown in Table 1.

Table 1. Values of electrical conductivity (EC) of water (ECa), EC of the initial solution (ECsol initial), EC of the final solution (ECsol final) and weighted EC (ECsolp) over time from experiments with replenishment strategies with fresh and brackish water

CEa	Fresh water replacement			Replacement with brackish water		
	Initial CEsol	$CEsol_{final}$	$CEsol_{p}$	Initial CEsol	$CEsol_{final}$	$CEsol_{p}$
	dS m^{-1}					
T1 = 0,30	2,10	2,02	1,92	2,01	2,08	1,95
T2 = 1,75	3,78	3,72	3,62	3,81	5,92	4,87
T3 = 3,50	5,56	5,42	5,41	5,57	8,46	6,77
T4 = 5,25	7,26	7,22	7,16	7,28	10,40	8.74

Source: Authors (2024).

4.6 Biometric measurements

4.6.1 Broccoli growth parameters

During the experiments, biometric measurements were performed on the plants. In the central position of each hydroponic channel, three plants were previously identified in the experiments with freshwater and brackish water replacement, ensuring that the measurements were always made on the same plants. The measurements included plant height (AP, in cm), stem diameter (DC, in mm), leaf area (AF, in cm²) and leaf number count (NF), which were performed 60 days after sowing, and at harvest, which occurred approximately 90 days after sowing and varied according to the strategy and treatment.

AF was measured via Equation 1, which estimates the leaf area of cauliflower (Silva *et al.*, 2021b), considering the length (CLF) and width (LLF) of the leaf blade. Owing to the biophysical similarity between broccoli and cauliflower, this estimation method was selected. Notably, leaves with symptoms of ionic deficiency or toxicity related to salinity or that presented damage caused by pests and diseases were not counted.

$$AF = 0.578 \times (CLF \times LLF)^{1.05} \quad (1)$$

When the inflorescences were harvested, in addition to the variables already mentioned, the fresh masses of the leaves (MFF, in g) and stems (MFC, in g) were obtained. The fresh mass of the aerial part (MFPA, in g) was calculated by the sum of the MFF and MFC. The DC was measured with a digital caliper. The fresh material was placed in paper bags and placed in a forced air circulation oven at 65°C until it reached a constant mass, allowing the quantification of the dry mass of the leaves (MSF, in g) and stems (MSC, in g). The dry mass of the aerial part (MSPA, in g) was obtained by the sum of the MSF and MSC.

4.6.2 Growth, production and visual quality of broccoli inflorescences

Broccoli inflorescences were harvested as soon as the ideal harvesting point was identified, which was determined by the compactness and firmness of the inflorescences. During each harvest, the inflorescence diameter (ID, in mm), inflorescence height (AI, in cm) and inflorescence fresh matter mass (MFI, in g) were determined.

In the experiment with freshwater replacement, harvests were performed at 45 days after transplanting (DAT) for treatments T1 and T2, at 50 DAT for treatment T3 and at 55 DAT for treatment T4. In the experiment with brackish water, the harvests of the T1 and T2 treatments also occurred at 45 DAT, whereas those of the T3 and T4 treatments were harvested at 51 and 57 DAT, respectively.

In both experiments, fresh inflorescences were placed in paper bags and placed in a forced hot air circulation oven at 65 °C until they reached constant mass to quantify the inflorescence dry matter mass (MSI, in g).

4.6.3 Water content of broccoli shoots and inflorescences

The water content (WC) was calculated on the basis of the fresh matter (FM) and dry matter (DM) masses of the leaves and inflorescence, according to Equation 2.

$$TA\ (\%) = (MF - MS)/MF \quad (2)$$

4.7 Salinity tolerance

To determine the tolerance of broccoli crops to salinity, the results of the experiment with freshwater replacement were used since salinity remained relatively constant, allowing the analysis of the relative production obtained in each treatment. The models of Maas and Hoffman (1977), Steppuhn, Van Genuchten and Grieve (2005a) and Bione *et al.* (2021) were used in the evaluation.

4.8 Statistical analysis

The data were evaluated individually for each experiment. First, the data were subjected to a normality test (Shapiro–Wilk test), and then, analysis of variance was performed via the F test (P ≤ 0.05). When the results were significant, regression analysis was performed, selecting first- or second-degree models, with the significance of their parameters assessed by Student's t test. In addition, the models were chosen on the basis of the highest values of the coefficient of determination (R^2 > 65%).

5 RESULTS AND DISCUSSION

5.1 Vegetative growth and water content in broccoli leaves

In the experiment in which water was replaced with fresh water, the plant height, number of leaves, stem diameter and leaf area were evaluated 60 days after sowing and at harvest. Additionally, at the time of inflorescence harvest, the fresh matter masses of the leaves, stem and aerial parts, as well as the dry matter masses of the leaves, stem and aerial parts, in addition to the water content of the leaves, were measured. The results are presented in Table 2.

Table 2. Summary of the F test and adjustment of the regression models for plant height (AP, cm), number of leaves (NF), leaf area (AF, cm^2), stem diameter (DC, mm), fresh leaf matter (MFF, g), fresh stem matter (MFC, g), fresh shoot matter (MFPA, g), dry leaf matter (MSF, g), dry stem matter (MSC, g), dry shoot matter (MSPA, g) and leaf water content (TAF, %) of broccoli plants grown under different levels of electrical conductivity of the nutrient solution (CEsol), in an NFT hydroponic system, at 60 days after sowing (DAS) and at harvest, in the experiment carried out with the freshwater replacement strategy.

Variables	***P* – F test value**	**CV (%)**	**Model or average**	**[1] Ratio (b/a) × 100**	**R^2 (%)**
			60 DAS		
AP	<0.01	4.93	AP = -3.52**CEsol + 73.03	4.82	88.84
NF	<0.01	6.19	NF = -0.58**CEsol + 16.34	3.56	90.42
A.D	<0.01	9.70	DC = -0.85**CEsol + 20.04	4.24	93.06
AF	<0.01	9.90	AF = -895.63**CEsol+13,743.24	6,52	82,58
			Colheita		
AP	<0,01	4,33	AP = -3,51**CEsol + 80,27	4,37	92,42
NF	<0,01	5,42	Média = 23,96	--	--
DC	<0,01	9,49	DC = -0,91*CEsol + 31,96	2,85	76,39
AF	<0,01	10,04	AF=-1.356,56**CEsol+19.336,80	7,02	90,64
MFF	<0,01	9,13	MFF = -39,42**CEsol + 787,88	5,00	94,55
MFC	<0,01	9,50	MFC = -48,41**CEsol + 906,36	5,34	90,91
MFPA	<0,01	8,38	MFPA = -87,83**CEsol+1.694,24	5,18	93,82
MSF	>0,05	7,62	Média = 80,30	--	--
MSC	<0,01	7,44	MSC = -2,31**CEsol + 73,96	3,12	92,41
MSPA	<0,01	4.13	MSPA = -3.93**CEsol + 161.57	2.43	98.70
TAF	<0.01	1.24	TAF = -0.66**CEsol + 89.53	0.74	87.85

CV – coefficient of variation; **, * – significant at 1% and 5%, respectively; [1] y = bx + a.
Source: Authors (2024).

According to Table 2, the electrical conductivity of the nutrient solution had a significant effect on all the parameters evaluated, except for NF and MSF at harvest. In general, in the experiment with freshwater replacement, the number of broccoli plant leaves was not affected by salinity, as evidenced by the absence of a significant effect (P > 0.05) of the salinity of the nutrient mixture on this parameter. Thus, even under saline stress, the plants continued to emit new leaves, although there were reductions in AF with increasing salinity in both periods evaluated.

In the experiment in which brackish water was used exclusively (Table 3), no significant effect (P > 0.05) on increasing the CEsol level was observed for NF and DC at 60 DAS or for MSC at harvest. However, CEsol significantly influenced the other parameters evaluated.

Table 3. Summary of F tests and fits of regression models for plant height (AP, cm), number of leaves (NF), leaf area (AF, cm ^{2}), stem diameter (DC, mm), leaf fresh matter (MFF, g), stem fresh matter (MFC, g), aerial part fresh matter (MFPA, g), leaf dry matter (MSF, g), stem dry matter (MSC, g), aerial part dry matter (MSPA, g) and leaf water content (TAF, %) of broccoli plants grown under different levels of electrical conductivity of the nutrient solution (CEsol) in an NFT hydroponic system at 60 days after sowing (DAS) and at harvest time for the experiment with replacement via brackish water.

Variables	***P* – F test value**	**CV (%)**	**Model or average**	**(1) Ratio (b/a) × 100**	**R 2 (%)**
			60 DAS		
AP	<0.01	8.27	AP = -2.83**CEsol + 65.34	4.33	95.95
NF	>0.05	11.89	Average = 13.00	--	--
A.D	>0.05	15.18	Average = 13.93	--	--
AF	<0.01	9.59	AF = -669.16**CEsol+11,617.06	5.76	87,30
			Colheita		
AP	<0,01	7,08	AP = -3,80**CEsol + 82,03	4,63	97,15
NF	<0,01	6,05	NF = -0,31*CEsol + 24,56	1,26	70,69
DC	<0,01	6,73	DC = -1,03**CEsol + 32,37	3,18	90,58
AF	<0,01	12,03	AF=-1.472,88**CEsol+17.911,24	8,22	82,45
MFF	<0,01	13,34	MFF = -46,39**CEsol + 754,53	6,15	83,96
MFC	<0,01	14,31	MFC = -63,56**CEsol + 913,64	6,96	84,67
MFPA	<0,01	10,37	MFPA =-109,95**CEsol+1.668,17	6,59	84,42
MSF	<0,01	11,19	MSF = -2,57**CEsol + 87,46	2,94	85,41
MSC	>0,05	14,43	Média = 59,78	--	--
MSPA	<0,01	8.15	MSPA = -4.07**ECsol + 155.63	2.62	89.13
TAF	<0.01	1.25	TAF = -1.02**ECsol + 90.18	1.13	79.77

CV – coefficient of variation; **, * – significant at 1% and 5%, respectively; (1) y = bx + a.
Source: Authors (2024).

At the end of the experiments, for each increase in ECsol, reductions in AF of 7.02 and 8.22% were recorded in the experiments with freshwater replacement (Table 2) and brackish water (Table 3), respectively. The reduction in leaf area is a mechanism by which plants adapt to stress, aiming to conserve water by reducing the transpiration area (Silva *et al*., 2017; Silva *et al*., 2019; Costa *et al*., 2020), as in the present study, in response to salinity stress. The magnitude of the AF reduction depends on the intensity and duration of saline stress, as does the water replacement strategy.

Contrary to what was observed in the present research, in the studies by Giuffrida *et al*. (2013a) and Giuffrida *et al*. (2017), the total AF of 'Conero' cauliflower was not significantly influenced by salinity. In the first study developed by the authors (2013), NaCl concentrations in the solution (0 mM NaCl - control, 20 and 40 mM NaCl) were evaluated. In the second study, two solutions (nonsaline - CEsol 2.0 dS m $^{-1}$ without NaCl and saline - CEsol 4.0 dS m $^{-1}$ with NaCl) were applied constantly throughout the cultivation cycle or in alternate growth periods. For the treatment in which the saline solution was applied until the emergence of inflorescence shoots (subsequently, a nonsaline solution was applied) and for the treatment in which the saline solution was applied immediately after the beginning of shoots (before that, a nonsaline solution was applied), the AF did not differ statistically from that of the control (nonsaline application throughout the cultivation cycle). These studies were carried out in pots with sand and cultivated in a greenhouse in Italy in the autumn–winter (90 DAT) and autumn (84 DAT) seasons.

In the present study, in the first evaluation (60 DAS), reductions in AF of 6.52% and 5.76% were recorded in the experiments with freshwater and brackish water, respectively, with an intensified effect on harvest (reductions of 7.02% and 8.22% per dS m $^{-1}$). These results are in agreement with those of Silva *et al*. (2020d), who evaluated the initial growth of cauliflower 'SF1758' via NFT hydroponics at the same location and reported that plants subjected to a water electrical conductivity (ECa) of 0.3 and 5.5 dS m $^{-1}$ presented a reduction in AF of 22.47% and 18.44% at 15 and 25 DAT, respectively, compared with the control treatment.

For the number of leaves, regardless of the CEsol level, the average recorded value was 23.96 leaves/plant in the experiment with fresh water (Table 2). In the experiment with brackish water (Table 3), an average of 23.95 leaves plant $^{-1 \text{ was estimated}}$ for the control treatment (with a weighted CEol of 1.95 dS m $^{-1}$), whereas the treatment with higher salinity (with a weighted CEol of 8.74 dS m $^{-1}$) resulted in 21.85 leaves plant $^{-1}$. Therefore, regardless of the replacement strategy, there was no significant leaf loss. Similarly, other studies have shown that the NF of cauliflower does not vary significantly as a function of the electrical conductivity of the saturated soil extract. De Pascale, Maggio and Barbieri (2005) studied CEsol equal to 1.81, 2.18, 2.89, 3.22 and 6.22 dS m $^{-1}$, finding an average NF of 28 leaf plants -1, whereas Costa *et al.* (2020) evaluated CEsol equal to 1.4, 2.6, 3.5, 4.6, 5.4 and 6.7 dS m $^{-1}$, recording an average NF of 27 $^{\text{leaf}}$ $_{\text{plants -1}}$.

In the study by Soares *et al*. (2020) with 'Piracicaba Precoce' cauliflower in NFT hydroponics, the number of leaves was shown to be quite variable depending on the electrical conductivity of the water (ECw) and the application rates of nutrient solutions (TAsol) in the cultivation channels. At 79 DAS (49 DAT), under low salinity (ECw 0.2 dS m $^{-1), \text{ 27.05 and 26.92 leaves plant -1}}$ were recorded with TAsol values of 1.5 and 2.5 L min $^{-1}$, respectively, whereas under relatively high salinity (ECw 5.5 dS m $^{-1}$), 18.84 and 14.23 leaves plant $^{-1 \text{ were recorded}}$, respectively. In this study, brackish water was used throughout the production process. Overall, the NFs observed in the present work (Tables 2 and 3) are within the range of values recorded by Soares *et al*. (2020).

The greater growth of broccoli leaves in the experiment with freshwater replacement contributed to greater accumulation of biomass, with higher MFPA averages of 1,525.61, 1,376.30, 1,219.08 and 1,065.38 g for weighted ECol levels of 1.92, 3.62, 5.41 and 7.16 dS m $^{-1}$, respectively. Under the brackish water replacement strategy, the average values obtained for MFPA were 1,453.77, 1,132.71, 923.81 and 707.21 g for weighted EC concentrations of 1.95, 4.87, 6.77 and 8.74 dS m $^{-1}$, respectively.

This greater reduction in biomass production under salinity in the experiment with brackish water replacement can be explained by the strategy used in the management of nutrient solutions, since brackish water was used exclusively (both for preparing the solutions and for replacing water consumption), which increased CEsol during cultivation. In contrast, in the strategy with fresh water replacement, CEsol remained relatively constant throughout the cycle, since brackish water was used only for preparing the solutions, whereas replacement was performed with low-salinity water.

5.3. Biometrics, production and water content of broccoli inflorescence

In the experiment in which brackish water was used only to prepare the nutrient solution, all harvested inflorescences were classified as marketable, without any shape defects or other disorders, as shown in Figure 2.

Figure 2. Visual quality of broccoli inflorescences under different levels of electrical conductivity of the nutrient solution (ECol) in an NFT hydroponic system in the experiment with freshwater replacement.

Source: Authors (2024).

Among the treatments tested in the experiment with brackish water replacement, the production of defective and unmarketable inflorescences was observed only at the highest salinity level (ECa = 5.25 dS m $^{-1}$), as illustrated in Figure 3. This reduction in the quality of the inflorescences can be attributed to high salinity stress, which affects the normal development of the plant, resulting in undesirable characteristics that compromise its commercial viability.

Figure 3. Visual quality of broccoli inflorescences grown under a water electrical conductivity of 5.25 dS m^{-1} in an NFT hydroponic system in an experiment with brackish water replacement

Source: Authors (2024).

During the experiment, no total plant losses were recorded due to the deleterious effects of excess salt, even at the highest salinity level tested. The symptoms presented and described in this study are compatible with the symptoms of sodium and chloride ion toxicity. According to Dias *et al.* (2016), high concentrations of NaCl can cause these spots to initially be on the edges and then intensify throughout the leaf area.

Although the literature concerning salinity has documented reductions in cauliflower inflorescence biomass, few studies have mentioned the loss of inflorescence quality (Giuffrida *et al*., 2017; Costa *et al*., 2020).

In the experiments performed, the inflorescence diameter, inflorescence height, fresh matter mass in the inflorescence, dry matter mass and water content in the inflorescence were evaluated. In both experiments, a significant effect of CEsol was observed for all the variables evaluated (DI, AI, MFI, MSI and TAI), except for the MSI of the experiment with freshwater replacement, as shown in Table 4.

Table 4. Summary of the F test and adjustment of the regression models for inflorescence diameter (DI, mm), inflorescence height (AI, mm), inflorescence fresh matter (MFI, g), inflorescence dry matter (MSI, g) and inflorescence water content (TAI, %) of broccoli grown under different levels of electrical conductivity of the nutrient solution (CEsol) in an NFT hydroponic system in the experiment carried out with a replacement strategy with fresh and brackish water.

Variables	*P* – F test value	CV (%)	Model or average	(1) Ratio (b/a) × 100	R^2 (%)
			Freshwater replacement experiment		
ID	<0.01	11.77	DI = – 8.95**CEsol + 123.73	7.23	93.53
THERE	<0.01	14.08	AI = -4.64**CEsol + 84.09	5.52	82.72
MFI	<0.01	6.08	MFI = -18.43**CEsol + 210.98	8.74	95.41
MSI	>0.05	6.71	Average = 20.13	--	--
TAI	<0.01	3.47	TAI = – 1.56**CEsol + 89.74	1.74	92.12
			Experiment with brackish water replacement		
ID	<0.01	6.56	DI = – 10.91**ECsol + 134.56	8.11	99.30
THERE	<0.01	12.17	AI = -7.79**CEsol + 102.96	7.57	97.20
MFI	<0.01	5.08	MFI = -27.62**CEsol + 262.83	10.51	95.49
MSI	<0.01	11.17	MSI = -2.05*CEsol + 30.63	6.69	99.44
TAI	<0.01	12.41	TAI = – 4.63**CEsol + 99.29	4.66	83.44

CV – coefficient of variation; **, * – significant at 1% and 5%, respectively; (1) y = bx + a.
Source: Authors (2024).

The estimated MFI means obtained in the experiment with freshwater replacement were 175.59, 144.26, 111.27 and 79.02 g for CEsol levels of 1.92, 3.62, 5.41 and 7.16 dS m^{-1}, respectively. In the experiment with brackish water replacement, the estimated MFI means were 208.97, 128.32, 75.84 and 21.43 g, respectively.

The lower broccoli production losses observed in the freshwater experiment can be attributed to the brackish water management strategy, which was used only to prepare the nutrient solution. In this experiment, the CEsol levels remained relatively constant throughout the cycle since the plants were watered with low-salinity water (CEw of 0.3 dS m^{-1}). With higher salinity (CEw of 5.25 dS m^{-1}), the average relative yield (RR) of IFM was approximately 60% greater than that of the control (RR = 100 × saline treatment/control), showing a reduction of approximately 8.74% for each unit increase in CEsol (Table 4).

On the other hand, in the experiment in which brackish water was used exclusively (both for the preparation of nutrient solutions and for water replacement), the CEsol levels increased, resulting in more pronounced production losses, with an average reduction of 10.51% for each unitary increase in CEsol.

This significant increase in CEsol occurred because of the greater water demand of broccoli during the growing season, leading to a greater contribution of toxic ions (mainly Na^{+}) to the nutrient solution. Thus, some of these ions were absorbed by the plants, while a significant amount remained in the solution, contributing to the increase in CEsol. Despite the considerable increases in CEsol, the fresh biomass yields of the inflorescences were satisfactory, except at the highest salinity level in the brackish water experiment.

In view of the above, it may be strategic to use brackish water only to prepare nutrient solutions, maintaining the replacement of plant water consumption with low-salinity water. Although these approaches represent different cultivation situations, the results of Giuffrida *et al.* (2017) with 'Conero' cauliflower grown in pots with sand during the fall are relevant. In this study, two solutions were applied: a nonsaline solution (CEsol of 2.0 dS m^{-1} without NaCl) and a saline solution (CEsol of 4.0 dS m^{-1} with NaCl), which were used continuously or in alternating periods. The authors reported that there was no significant difference in MFI when the saline solution was applied until the emergence of inflorescence shoots (subsequently, a nonsaline solution was applied) compared with the control. Furthermore, production under application of the solutions in alternating growth periods did not differ statistically from production under constant application throughout the production cycle.

In the present study, in both strategies, the reduction in MFI was influenced by inflorescence diameter and inflorescence height. In the experiment with freshwater replacement, the average DI ranged from 106.55 mm to 59.65 mm for CEsol levels from 1.92 to 7.16 dS m^{-1}, showing a reduction of 7.23% for each unit increase in CEsol. For the AI, the averages were 75.18 mm and 50.87 mm at the same CEsol levels, with a reduction of 5.52% per unit increase.

In the brackish water experiment, the average ID ranged from 113.29 mm to 39.21 mm for CEsol levels from 1.95 to 8.74 dS m^{-1}, resulting in a reduction of 8.11% per unit increase in CEsol. For the AI, the averages were 87.77 mm and 34.88 mm at the corresponding CEsol levels, with a reduction of 7.57% per unit increase.

In accordance with the results of the present study, in both replacement strategies, except for the highest salinity level of the experiment with the exclusive use of brackish water, Giuffrida *et al*. (2013b) reported that the shape of the cauliflower head was not affected by the NaCl concentration in the nutrient solution (0 mM NaCl, control; 20 and 40 mM NaCl).

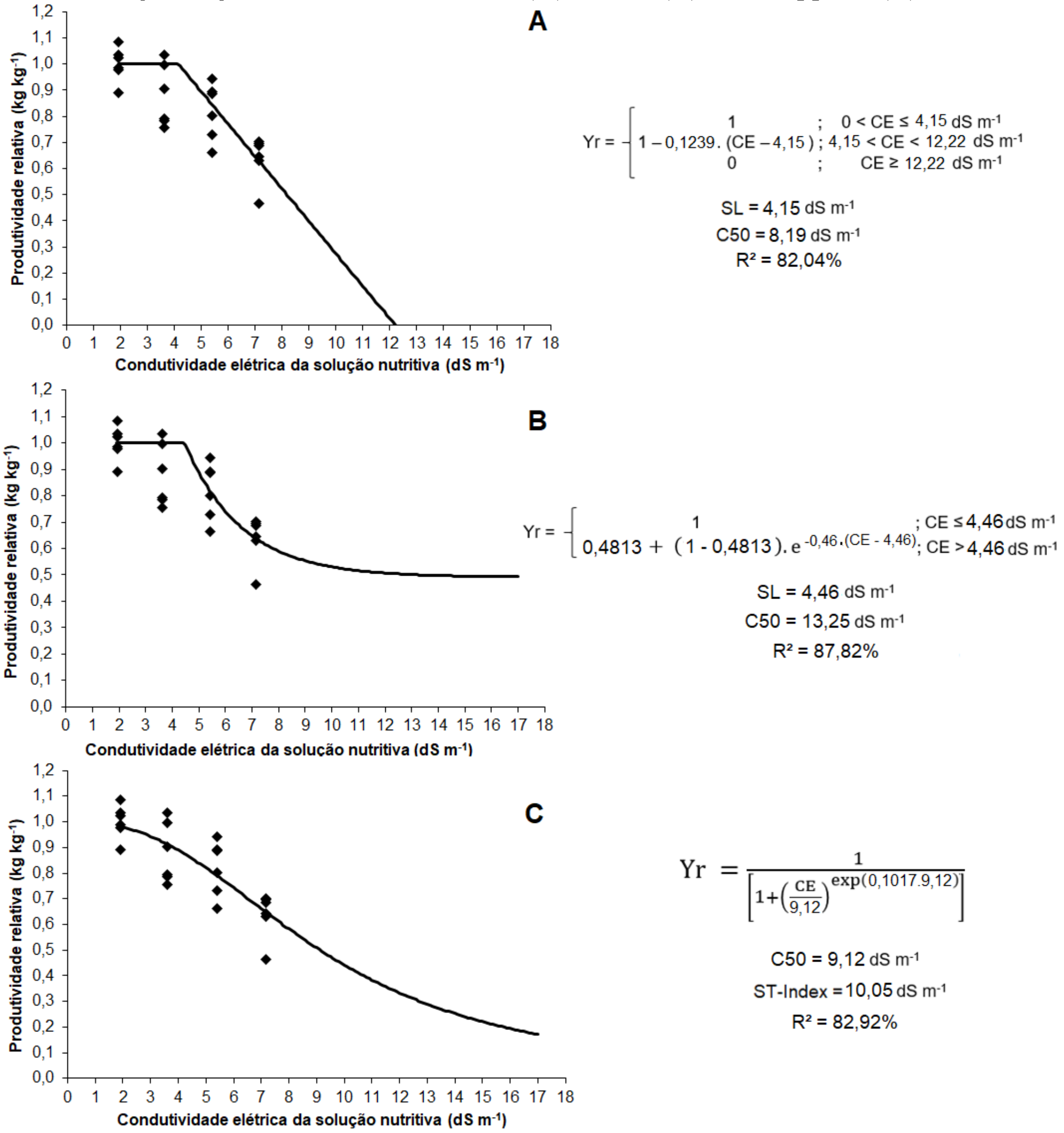
Owing to the larger surfaces of the inflorescences observed in the freshwater experiment, there was greater accumulation of water in the tissues, resulting in higher MFI production. The impact of the salinity of the nutrient mixture on the water content in the inflorescence was more pronounced in the brackish water experiment, with a percentage reduction of 4.66% per increase in salinity, which was greater than the 2.92% recorded in the freshwater experiment.

This significant impact of salinity on the water content of the inflorescence became more evident when the salinity levels of each experiment were compared. In the experiment with freshwater replacement, an estimated TAI of 78.57% was obtained for the salinity level of 7.16 dS $m^{-1;}$ in the experiment with brackish water, the average salinity level (CEsolp = 8.74 dS m^{-1}) was 58.82%.

5.4 Broccoli tolerance to salinity

The analysis of the relative production data, which was based on the data from the control treatment, allowed the threshold salinity (SL) of broccoli to be determined via the Maas and Hoffman (Figure 4A) and Bione (Figure 4B) models. The value obtained was 4.15 dS m^{-1} for the Maas and Hoffman models, which indicates a reduction of 12.39% for each unit increase in CEsol and 4.46 dS m^{-1} for the Bione model. Notably, the Bione model presented an advantage of 5.78% over the Maas and Hoffman models in terms of the coefficient of determination.

Figure 4. Relative productivity (Yr) and threshold salinity of broccoli in an NFT hydroponic system under different levels of electrical conductivity of the nutrient solution, as analyzed by the Maas and Hoffman (A), Bione (B) and Steppuhn (C) models.



Source: Authors (2024).

According to Maas and Hoffman (1977), the threshold salinity of broccoli is 2.8 dS m^{-1}, with a reduction of 9.2% for each unitary increase in salinity, characterizing the crop as moderately sensitive. In the present study, the values obtained (4.15 dS m $^{-1}$ and 12.39%) were higher than those reported by the aforementioned authors, indicating a greater tolerance of broccoli to salinity under hydroponic cultivation conditions. However, using the tolerance ranges of Maas (1984) to reclassify the sensitivity of broccoli to salinity is questionable since these ranges were developed for soil cultivation and are based on the electrical conductivity of the saturation extract.

The Steppuhn model (Figure 4C) does not exhibit a 100% yield plateau followed by a decline; instead, it introduces the concept of C50, which represents the salinity at which the yield reaches 50% of the yield relative to that of the control treatment. For broccoli, the C50 value was 9.12 dS m^{-1}, whereas in the Maas and Hoffman and Bione models, the C50 values were 8.19 and 13.25 dS m^{-1}, respectively.

Additionally, on the basis of the results of the Steppuhn model, the salinity tolerance index (ST index) of broccoli was 10.05 dS m^{-1}, with a slope 's' of 0.1017 (dS $m^{-1})^{-1}$. Steppuhn, Van Genuchten and Grieve (2005b) reported, in studies with broccoli grown in soil, an index of 8.99 dS m^{-1}, associated with a C50 of 7.88 dS m^{-1} and a slope 's' of 0.14 (dS $m^{-1})^{-1}$.

6 CONCLUSIONS

The results of this study suggest that broccoli cultivation is viable under an electrical conductivity of the nutrient solution of up to 4.46 dS m^{-1}. In general, the inflorescences were highly productive, and there were no significant losses in quality that compromised the viability of the plants, except at the highest salinity level (ECw = 5.25 dS m^{-1}) in the experiment in which brackish water was used exclusively. Therefore, the exclusive use of brackish water with an ECw of 5.25 dS m^{-1} should be avoided, and these waters should be preserved only for the preparation of nutrient solutions to prevent possible adverse effects on the quality of the inflorescences.

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