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Growth and yield of cauliflower with brackish waters under hydroponic conditions[1]

Crescimento e produção da couve-flor com águas salobras em condições hidropônicas

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HIGHLIGHTS:

Number of leaves and leaf blade length/leaf blade width ratio were not affected by brackish waters (0.3-5.5 dS m⁻¹).
Cauliflower water consumption decreased 6.01 and 11.51% per dS m⁻¹ in winter-spring and spring-summer, respectively.
In winter-spring, the water use efficiency of inflorescences was not affected by brackish waters, with mean of 21.62 kg m⁻³.

ABSTRACT: Historically, and in the aggravating climate change scenario, droughts are increasingly severe in arid and semi-arid regions, limiting the use of irrigation. As an alternative for these regions, brackish waters have been used, despite the severe risks of soil salinization, as well as losses in crop production and quality. Thus, the adoption of adequate technologies should mitigate or control the impacts caused by salt stress. Therefore, in the present study two experiments were conducted to evaluate the cultivation of cauliflower with brackish waters using a nutrient film technique (NFT) hydroponic system from July to October 2019 (winter-spring) and from October 2019 to January 2020 (spring-summer). Cauliflower plants were subjected to six values of ECw: 0.3 - control (without NaCl), 1.5, 2.5, 3.5, 4.5, and 5.5 dS m^{-1} (with NaCl), in a randomized block design with six replicates. For the leaf blade area at inflorescence harvest, reductions per dS m^{-1} increment in ECw of 7.22 and 6.41% were found in the winter-spring and spring-summer experiments, respectively. The quality losses of cauliflower inflorescences were more pronounced in the spring-summer experiment, varying according to the ECw used. Therefore, it is possible to grow cauliflower hydroponically under ECw of up to 5.5 dS m^{-1}; however, in the hottest seasons these waters should be reserved and used only for the preparation of nutrient solutions or replacement of water consumed by plants.

Key words: *Brassica oleracea* var. *botrytis*, inflorescence yield, salt stress, soilless cultivation, water resources

RESUMO: Historicamente e com o agravamento das mudanças climáticas, nas regiões áridas e semiáridas as secas são cada vez mais severas, limitando-se o uso da irrigação nas culturas. Como solução para essas regiões, as águas salobras têm sido utilizadas, mesmo sabendo-se dos graves riscos de salinização dos solos, bem como das perdas de produção e qualidade dos produtos colhidos. Assim, a adoção de tecnologias adequadas deve mitigar ou controlar os impactos causados pelo estresse salino. Portanto, no presente estudo foram realizados dois experimentos visando avaliar o cultivo da couve-flor com águas salobras usando o sistema hidropônico NFT (técnica do fluxo laminar de nutrientes) entre julho e outubro de 2019 (inverno-primavera) e outubro de 2019 e janeiro de 2020 (primavera-verão). As plantas foram submetidas a seis valores de CEa: 0,3 - controle (sem NaCl); 1,5; 2,5; 3,5; 4,5 e 5,5 dS m^{-1} (preparadas com NaCl), no delineamento em blocos casualizados com seis repetições. Na colheita das inflorescências foram encontradas reduções por dS m^{-1} de incremento na CEa de 7,22 e 6,41% para a área do limbo foliar nos experimentos de inverno-primavera e primavera-verão, respectivamente. As perdas de qualidade das inflorescências da couve-flor foram mais acentuadas no experimento da primavera-verão, variando de acordo com a CEa usada. Portanto, é possível o cultivo da couve-flor sob CEa de até 5,5 dS m^{-1}; porém, nas estações mais quentes essas águas devem ser reservadas e usadas apenas para o preparo das soluções nutritivas ou para reposição do consumo hídrico das plantas.

Palavras-chave: *Brassica oleracea* var. *botrytis*, rendimento da inflorescência, cultivo sem solo, estresse salino, recursos hídricos

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Introduction

In arid and semi-arid regions, due to the scarcity of freshwater (Silva et al., 2020a), brackish waters have often been used to irrigate crops (Silva et al., 2020b; Silva et al., 2021a). However, the use of these waters can increase the risk of soil salinization, thus depreciating cultivated areas, in addition to reducing crop yield expectations (Bione et al., 2021).

To mitigate salinity problems when brackish waters are used, different strategies have been adopted to take advantage of these waters. Therefore, the transition from conventional soil cultivation systems to the soilless cultivation system (hydroponics) stands out (Atzori et al., 2019; Silva et al., 2018; Silva et al., 2022). In addition to leafy vegetables, such as parsley (Martins et al., 2019), endive (Silva et al., 2020b), coriander (Silva et al., 2020c), lettuce (Silva et al., 2021b), and rocket (Silva et al., 2022), it has been possible to cultivate species with longer cycles, such as cauliflower (Costa et al., 2020; Santos et al., 2021).

The cultivation of cauliflower (*Brassica oleracea* var. *botrytis*) proved to be viable using brackish waters only in the preparation of the nutrient solutions under the climatic conditions of Cruz das Almas-BA, in the Brazilian Northeast (Costa et al., 2020). Differently, in the present study the brackish waters are used both in the preparation of the solutions and for replacing the water consumed by the plants, aiming to evaluate the cultivation of cauliflower using an nutrient film technique (NFT) hydroponic system.

Material and Methods

Two experiments were carried out with cauliflower in a greenhouse, one from July to October 2019 (winter-spring season) and the other from October 2019 to January 2020 (spring-summer season). The facilities at the site of the experiments are part of the experimental area of the Programa de Pós-Graduação em Engenharia Agrícola of the Universidade Federal do Recôncavo da Bahia (UFRB), Cruz das Almas-BA (12° 40' 19" S, 39° 06' 23" W and altitude of 220 m a.s.l), Brazil.

Outside the greenhouse, the mean air temperature and relative humidity were 22.5 ± 1.1 °C and 89.1 ± 4.50% and 25.8 ± 0.9 °C and 80.84 ± 5.19% for the winter-spring and spring-summer experiments, respectively. Data were obtained from an automatic weather station installed near the experimental area, on the premises of UFRB.

Cauliflower plants were grown under six values of electrical conductivity of water (ECw): 0.3 - control, 1.5, 2.5, 3.5, 4.5, and 5.5 dS m^{-1}, in a randomized block design with six replicates. The saline waters were used both for the preparation of the solutions and for replacing the water consumed by plants. The ECw values, except for the control, were obtained by the addition of 0.714, 1.377, 1.888, 2.399, and 3.153 g L^{-1} NaCl in tap water (ECw 0.3 dS m^{-1}) using the relationship between ECw and the concentration of salts [concentration ($mmol_c$ L^{-1}) ≅ 10 × ECw (dS m^{-1})] reported by Richards (1954). A modification was performed in this expression to determine the quantity of salts in g L^{-1}, resulting in Eq. 1.

$$Q_{NaCl} = \frac{\left[58.44 \times \left(ECw - 0.3\right)\right]}{100} \quad (1)$$

where:

Q_{NaCl} - quantity of NaCl to be added (g L^{-1}), considering the salts present in the tap water (ECw of 0.3 dS m^{-1});

ECw - desired value for the electrical conductivity of water (dS m^{-1}); and,

58.44 - molar mass of NaCl (g mol^{-1}).

Cauliflower was grown using an nutrient film technique (NFT) hydroponic system, consisting of 6 m long channels made of PVC pipes of 0.075 m in diameter, and slope of 3.0%. Two channels were arranged per bench, maintaining a 0.56 × 0.80 m distance between plants and channels, respectively. Details of the experimental structure are described in Costa et al. (2020). The circulation of the nutrient solutions was controlled using an analog timer, with circulations programmed at alternate intervals of 15 min from 6:00 a.m. to 6:00 p.m.; at night, the nutrient solutions were circulated every two hours, with each event lasting 15 min.

The sowing of the cauliflower cv. 'SF1758' (Feltrin® Sementes, Farroupilha, Brazil) was carried out on July 10 and October 10, 2019, for the winter-spring and spring-summer experiments, respectively. Seeds were sown in phenolic foam (2 × 2 × 2 cm), two per cell. At five and eight days after sowing (DAS) for the winter-spring and spring-summer experiments, respectively, thinning was performed, leaving only one seedling per cell. Then, the seedlings were taken to a nursery (NFT system) built with a corrugated PVC roof sheet, where they received a nutrient solution (Furlani et al., 1999) with 50% concentration (electrical conductivity of the solution - ECsol ~ 1.0 dS m^{-1}) for periods of 25 and 21 days, respectively.

At 30 and 29 DAS in winter-spring and spring-summer, respectively, the cauliflower seedlings were transplanted to the hydroponic channels. In total, nine seedlings were transplanted per channel, spaced at 0.56 m. In the definitive cultivation system, the plants received a nutrient solution (Furlani et al., 1999) with 100% concentration, prepared in water with different electrical conductivities by the addition of NaCl, as shown in Table 1. During the experiments, the values of ECsol and pHsol were measured periodically (two to three times a week). Following the same criterion adopted by Costa et al. (2020), in the present study the nutrient solutions were managed by proportionally replacing the nutrients consumed

Table 1. Values of electrical conductivity of water (ECw), initial ($ECsol_{initial}$) and final solution ($ECsol_{final}$) of experiments

ECw	Winter-spring		Spring-summer	
	$ECsol_{initial}$[1]	$ECsol_{final}$[2]	$ECsol_{initial}$[1]	$ECsol_{final}$[2]
	(dS m^{-1})			
0.3 - control	1.95	1.43 ± 0.22	1.92	1.86 ± 0.31
1.5	3.19	6.30 ± 0.45	3.30	9.32 ± 0.71
2.5	4.13	8.45 ± 0.70	4.11	12.05 ± 0.76
3.5	5.17	9.92 ± 0.90	5.03	15.91 ± 0.79
4.5	6.07	11.34 ± 1.15	6.11	18.75 ± 1.04
5.5	7.12	13.20 ± 0.37	7.09	20.87 ± 0.96

[1] - At the beginning of the experiments, the ECsol values were the same for six replicates of the respective treatment. [2] - Means of ECsol with standard deviation (n = 6) in the final of the experiments

by the plants when observing a decrease of 50% in the ECsol of the control treatment. ECsol values were maintained for all treatments.

During the experiments, biometric measurements were carried out on the plants. In the central part of each hydroponic channel, three plants were identified and biometric measurements were always carried out on the same plants. In these previously identified plants, measurements of leaf blade length (LBL, cm), leaf blade width (LBW, cm), and number of leaves (NL) were performed at 20, 30, and 40 days after transplanting (DAT) in winter-spring and at 15, 25, 35, and 45 DAT in spring-summer.

LBL and LBW measurements were performed on the youngest sixth fully expanded leaf according to Silva et al. (2021c). LBL measurement was performed parallel to the direction of the midrib from the apex of the lamina to the base of the petiole. LBW was measured at the widest point perpendicular to the main axis of the leaf. The selected leaves showed no symptoms of mineral deficiency or toxicity that could be attributed to salinity, or damage caused by pests and/or diseases.

From the measurements of LBL and LBW, the LBL/LBW ratio was calculated, and the leaf blade area (LBA, cm^2 per leaf) was also estimated according to Eq. 2, developed by Silva et al. (2021c) for the same cauliflower cultivar. In all evaluations, this equation was used, except in the harvest of the winter-spring experiment (LBL and LBW were not measured), when LBA was measured using a portable leaf area meter model CI202 (CID Bio-Science, Inc., Washington, USA).

$$\mathrm{LBA} = -22.610 + 0.928 \times \mathrm{LBL} \times \mathrm{LBW} \quad \left(R^2 = 97.93\%\right) \tag{2}$$

where:

LBA - leaf blade area (cm^2 per leaf);
LBL - leaf blade length (cm); and,
LBW - leaf blade width (cm).

When harvesting cauliflower inflorescences, in addition to the same variables previously described, plant height (PH, cm), stem diameter (SD, mm), leaf fresh matter (LFM, g), and stem fresh matter (SFM, g) were also measured. Shoot fresh matter (ShFM, g) was obtained by the sum of LFM and SFM. SD was measured using a digital caliper. Immediately after weighing of the fresh plants, the material was placed in paper bags and dried in a forced-air oven at a temperature of 65 °C until reaching constant weight, to quantify leaf dry matter (LDM, g) and stem dry matter (SDM, g). Shoot dry matter (ShDM, g) was obtained by the sum of LDM and SDM.

The cauliflower inflorescences were harvested as the point of harvest was identified. The harvest period extended by five days (from 56 to 60 DAT) in winter-spring and by 11 days (from 48 to 58 DAT) in spring-summer. As a criterion for harvesting, the compactness and firmness of the inflorescences were considered. In each harvest, inflorescence diameter (ID, cm), inflorescence length (IL, cm), and inflorescence fresh matter (IFM, g) were determined. The ID/IL ratio was calculated.

The fresh inflorescences (only one from each plot) were placed in paper bags and dried in a forced-air oven at a temperature of 65 °C until reaching constant weight, to quantify the inflorescence dry matter (IDM, g).

For each plot (hydroponic channel) an average was obtained for IFM as a function of the number of inflorescences produced. For the averages, only marketable inflorescences were considered. Non-marketable inflorescences were characterized as those weighing less than 100 g, with a lack of compactness (shallow), rot (caused by boron deficiency), hairy (characterized by the opening of head flowers), and with pinkish spots. Therefore, the percentage of losses (non-marketable inflorescences) per treatment was calculated in relation to the total number of inflorescences produced in the respective treatment.

The yield in kg ha^{-1} was also calculated from the average IFM yields, considering 0.448 m^2 of area occupied per plant (spacing of 0.56 × 0.80 m between plants and hydroponic channels, respectively).

Water content (WC) was calculated based on the fresh (FM) and dry (DM) matter of leaves, shoots, and inflorescences, according to the methodology of Benincasa (2003) using Eq 3:

$$\mathrm{WC}(\%) = \frac{(\mathrm{FM} - \mathrm{DM})}{(\mathrm{FM})} \times 100 \tag{3}$$

Water consumption (WC) per plant was determined daily, by dividing the volume of nutrient solution consumed by the number of plants in the plot (hydroponic channel). From the daily records, the accumulated WC (L per plant) during the entire cauliflower cycle (period from transplanting to harvesting) was calculated. Water use efficiency (WUE, kg m^{-3}) was calculated based on the ratio between the production of leaves (LFM or LDM) or inflorescences (IFM or IDM) and the accumulated WC per plant.

The data of each experiment were subjected to the normality test (Shapiro-Wilk) and subsequently analyzed according to the analysis of variance by F-test ($p \le 0.05$) and by regression analysis, selecting the first- or second-degree model, and the significance of their parameters was evaluated by the Student's t-test. For the variables described by the first-degree model ($y = a + bx$), the relative decrease per unit increase of ECw was calculated, using the relation: $(b/a) \times 100$; where: a is the linear coefficient and b is the intercept. Statistical analysis was performed using the SISVAR 5.3 statistical program (Ferreira, 2011).

Results and Discussion

The results of the winter-spring experiment are presented in Table 2 (number of leaves - NL, leaf blade length - LBL, leaf blade width - LBW, LBL/LBW ratio, leaf blade area - LBA, plant height - PH, stem diameter - SD, leaf fresh matter - LFM, stem fresh matter - SFM, shoot fresh matter - ShFM, leaf dry matter - LDM, stem dry matter - SDM, shoot dry matter - ShDM, water content in leaves - WCL, and water content in the shoot - WCS). There was no significant effect ($p > 0.05$) on NL and LBL/LBW ratio caused by the increasing ECw values in the evaluations

Table 2. Summary of the F-test and fit of regression models for number of leaves (NL), leaf blade length (LBL, cm), leaf blade width (LBW, cm), LBL/LBW ratio, leaf blade area (LBA, cm^2 per leaf), plant height (PH, cm), stem diameter (SD, mm), leaf fresh matter (LFM, g per plant), stem fresh matter (SFM, g per plant), shoot fresh matter (ShFM, g per plant), leaf dry matter (LDM, g per plant), stem dry matter (SDM, g per plant), shoot dry matter (ShDM, g per plant), water content in leaves (WCL, %), and water content in the shoot (WCS, %) of cauliflower plants grown under different electrical conductivities of water (ECw) using an NFT hydroponic system, at 20, 30, and 40 days after transplanting (DAT) and at harvest in the winter-spring experiment

Variables	p-value	CV (%)	Model or mean	(1)Relation (b/a) × 100	R^2 (%)
			20 DAT		
NL	> 0.05	10.07	NL = mean = 18.30	--	--
LBL	≤ 0.05	13.92	LBL = 18.565 - 0.846**ECw	4.56	80.24
LBW	≤ 0.001	12.59	LBW = 14.637 - 0.618**ECw	4.22	73.24
LBL/LBW ratio	> 0.05	5.35	LBL/LBW ratio = mean = 1.25	--	--
LBA	≤ 0.001	26.75	LBA = 229.165 - 18.790**ECw	8.20	75.35
			30 DAT		
NL	> 0.05	9.87	NL = mean = 19.92	--	--
LBL	> 0.05	15.51	LBL = mean = 18.22	--	--
LBW	> 0.05	14.69	LBW = mean = 14.48	--	--
LBL/LBW ratio	> 0.05	4.89	LBL/LBW ratio = mean = 1.26	--	--
LBA	≤ 0.05(2)	30.30	LBA = mean = 228.47	--	--
			40 DAT		
NL	> 0.05	7.99	NL = mean = 21.30	--	--
LBL	≤ 0.001	14.10	LBL = 24.461 - 1.217**ECw	4.98	67.49
LBW	≤ 0.001	14.26	LBW = 19.226 - 0.892**ECw	4.64	68.26
LBL/LBW ratio	> 0.05	5.27	LBL/LBW ratio = mean = 1.26	--	--
LBA	≤ 0.001	25.02	LBA = 402.668 - 33.426**ECw	8.30	65.06
			Harvest (from 56 to 60 DAT)		
NL	> 0.05	8.95	NL = mean = 24.72	--	--
LBA	≤ 0.05	27.45	LBA = 590.219 - 42.642**ECw	7.22	72.94
PH	≤ 0.001	7.93	PH = 46.304 - 2.101**ECw	4.54	91.50
SD	≤ 0.001	9.16	SD = 14.169 - 0.663**ECw	4.68	76.84
LFM	≤ 0.001	23.03	LFM = 556.711 - 42.632**ECw	7.66	78.29
SFM	≤ 0.001	18.77	SFM = 61.215 - 5.401**ECw	8.82	79.06
ShFM	≤ 0.001	23.59	ShFM = 626.915 - 48.102**ECw	7.67	75.95
LDM	≤ 0.001	10.69	LDM = 49.824 - 5.157**ECw	10.35	83.68
SDM	≤ 0.001	23.32	SDM = 7.994 - 0.691**ECw	8.64	85.17
ShDM	≤ 0.001	10.45	ShDM = 57.818 - 5.848**ECw	10.11	84.89
WCL	> 0.05	2.43	WCL = mean = 91.68	--	--
WCS	> 0.05	2.63	WCS = mean = 91.32	--	--

CV - Coefficient of variation; ** - Significant at p ≤ 0.01 by t-test; (1) - y = a + bx; (2) - There was no satisfactory fit of data to any regression model

performed at 20, 30, and 40 DAT. ECw significantly influenced LBL, LBW, and LBA at 20 and 40 DAT. At 30 DAT, there was significant effect ($p \leq 0.05$) of ECw only on LBA; however, there was no satisfactory fit of any regression model to describe the data. For the variables obtained at harvest (from 56 to 60 DAT), there was no significant effect ($p > 0.05$) of ECw on NL, WCL, and WCS. For the spring-summer experiment (Table 3), there was no significant effect ($p > 0.05$) of ECw on the LBL/LBW ratio (for any evaluation period) and on NL (at 15 and 25 DAT). In the other evaluations, NL was significantly influenced by ECw, as well as the other variables in all evaluations.

In general, regardless of the evaluation dates, the LBL/LBW ratio of the cauliflower leaves was not affected by salinity ($p > 0.05$) (Tables 2 and 3). NL also was not affected by ECw in the winter-spring experiment, with a mean of 24.72 leaves per plant recorded at the inflorescence harvest (Table 2). In the case of the experiment carried out in the spring-summer (Table 3), due to the contribution of salts from brackish waters used for replacing the water consumed by the plants, the ECsol values increased more markedly (Table 1), consequently causing decrease in NL from the evaluation performed at 35 DAT. In the final evaluation, 29.7 leaves per plant were estimated under cultivation conditions without salt stress (ECw 0.3 dS m^{-1}), while under the highest electrical conductivity (ECw 5.5 dS m^{-1}) a total of 23.8 leaves per plant was estimated.

Therefore, in the present study, regardless of the season of the year and ECw values, no greater losses of cauliflower leaves were identified. As observed for cauliflower, responses of different plant species to salt stress can be related to growing season, level of salinity applied, cultivation method, among other factors (Cova et al., 2017; Silva et al., 2022). According to Ur Rahman et al. (2021), plants develop different mechanisms to survive to salt stress including morphological changes, such as decrease in number of leaves, plant height, leaf area, biomass, among others. These reductions can be attributed to the difficulty of plants in absorbing water because the osmotic potential decreases (Silva et al., 2016; Silva et al., 2021b), which leads to the closure of stomata and suppression of photosynthesis (Zahra et al., 2022; Targino et al., 2023).

As recorded in the present study, even under salt stress, the plants continued to produce new leaves, but with lower LBA; similar results were recorded by other authors in cauliflower (Giuffrida et al., 2017; Costa et al., 2020). For LBA in the winter-spring experiment, reductions per dS m^{-1} increment in ECw of 8.20, 8.30, and 7.22% were found at 20, 40 DAT and inflorescence harvest, respectively (Table 2). For spring-summer (Table 3), there was a reduction in LBA of 4.62% with each unit increase in ECw at 15 DAT, intensifying the effect of water salinity in the following evaluations (25, 35, 45 DAT and inflorescence harvest), with 5.54, 6.05, 6.54, and

Table 3. Summary of the F-test and fit of regression models for number of leaves (NL), leaf blade length (LBL, cm), leaf blade width (LBW, cm), LBL/LBW ratio, leaf blade area (LBA, cm^2 per leaf), plant height (PH, cm), stem diameter (SD, mm), leaf fresh matter (LFM, g per plant), stem fresh matter (SFM, g per plant), shoot fresh matter (ShFM, g per plant), leaf dry matter (LDM, g per plant), stem dry matter (SDM, g per plant), shoot dry matter (ShDM, g per plant), water content in leaves (WCL, %), and water content in the shoot (WCS, %) of cauliflower plants grown under different electrical conductivities of water (ECw) using an NFT hydroponic system, at 15, 25, 35, and 45 days after transplanting (DAT) and at harvest in the spring-summer experiment

Variables	p-value	CV (%)	Model or mean	[(1)]Relation (b/a) × 100	R^2 (%)
			15 DAT		
NL	> 0.05	4.86	NL = mean = 10.63	--	--
LBL	≤ 0.001	4.65	LBL = 16.966 - 0.444**ECw	2.61	95.69
LBW	≤ 0.001	4.83	LBW = 12.922 - 0.234**ECw	1.81	73.16
LBL/LBW ratio	> 0.05	3.99	LBL/LBW ratio = mean = 1.28	--	--
LBA	≤ 0.001	9.56	LBA = 180.337 - 8.341**ECw	4.62	90.54
			25 DAT		
NL	> 0.05	3.71	NL = mean = 15.79	--	--
LBL	≤ 0.001	5.31	LBL = 22.411 - 0.615**ECw	2.74	91.73
LBW	≤ 0.001	5.29	LBW = 17.691 - 0.518**ECw	2.93	97.71
LBL/LBW ratio	> 0.05	4.00	LBL/LBW ratio = mean = 1.28	--	--
LBA	≤ 0.001	10.12	LBA = 343.942 - 19.071**ECw	5.54	95.23
			35 DAT		
NL	≤ 0.001	5.00	NL = 22.246 - 0.583**ECw	2.62	82.47
LBL	≤ 0.001	4.11	LBL = 24.625 - 0.738**ECw	3.00	80.70
LBW	≤ 0.001	3.88	LBW = 19.156 - 0.603**ECw	3.15	86.18
LBL/LBW ratio	> 0.05	2.94	LBL/LBW ratio = mean = 1.29	--	--
LBA	≤ 0.001	8.02	LBA = 415.223 - 25.109**ECw	6.05	82.54
			45 DAT		
NL	≤ 0.001	6.85	NL = 28.390 - 1.480**ECw	5.21	72.84
LBL	≤ 0.001	4.10	LBL = 26.067 - 0.898**ECw	3.45	92.72
LBW	≤ 0.001	3.36	LBW = 19.975 - 0.666**ECw	3.33	92.69
LBL/LBW ratio	> 0.05	2.46	LBL/LBW ratio = mean = 1.30	--	--
LBA	≤ 0.001	7.70	LBA = 459.593 - 30.045**ECw	6.54	91.92
			Harvest (from 48 to 58)		
NL	≤ 0.001	5.47	NL = 29.998 - 1.129**ECw	3.76	66.49
LBL	≤ 0.001	4.31	LBL = 26.735 - 0.915**ECw	3.42	94.14
LBW	≤ 0.001	4.09	LBW = 20.522 - 0.664**ECw	3.24	93.02
LBL/LBW ratio	> 0.05	2.79	LBL/LBW ratio = mean = 1.30	--	--
LBA	≤ 0.001	8.67	LBA = 485.515 - 31.140**ECw	6.41	93.60
PH	≤ 0.001	4.63	PH = 46.302 - 2.046**ECw	4.42	82.47
SD	≤ 0.001	7.68	SD = 17.137 - 0.943**ECw	5.50	92.16
LFM	≤ 0.001	12.69	LFM = 709.370 - 148.200**ECw + 16.806**ECw^2	--	95.06
SFM	≤ 0.001	15.62	SFM = 105.483 - 24.754**ECw + 2.583**ECw^2	--	99.52
ShFM	≤ 0.001	12.48	ShFM = 814.853 - 172.954**ECw + 19.389**ECw^2	8.51	96.04
LDM	≤ 0.05	17.47	LDM = 75.630 - 3.901**ECw	5.16	81.53
SDM	≤ 0.001	14.39	SDM = 15.574 - 1.231**ECw	7.91	95.85
ShDM	≤ 0.001	16.61	ShDM = 91.205 - 5.132**ECw	5.63	88.25
WCL	≤ 0.001	1.87	WCL = 89.520 - 2.635**ECw + 0.368**ECw^2	--	91.94
WCS	≤ 0.001	1.79	WCS = 88.916 - 2.667**ECw + 0.372**ECw^2	--	93.34

CV - Coefficient of variation; ** - Significant at $p \leq 0.01$ by t-test; [(1)] - y = a + bx

6.41% reductions per dS m^{-1} increment in ECw, respectively. At inflorescence harvest, in the control treatment (ECw 0.3 dS m^{-1}), LBA means of 577.43 and 476.17 cm^2 per leaf were estimated in winter-spring (Table 2) and spring-summer (Table 3), respectively.

Still, at the inflorescence harvest, the decreases were less pronounced for PH and SD than for LBA; for each unit increase in ECw, these reductions were equal to 4.54 and 4.68% in winter-spring (Table 2) and 4.42 and 5.50% in spring-summer (Table 3), respectively. Regarding the LFM of cauliflower plants, its reduction of 7.66% per unit increase in ECw is compatible with that found for LBA in winter-spring (Table 2). The highest means of LFM and ShFM were estimated under the control treatment (ECw 0.3 dS m^{-1}), 543.92 and 612.48 g per plant in winter-spring (Table 2) and 666.42 and 764.71 g per plant in spring-summer (Table 3), respectively.

While in the winter-spring experiment the water status of the cauliflower plants was not affected by the increasing ECw levels (means for WCL and WCS of 91.68 and 91.32%, respectively) (Table 2), in the spring-summer experiment (Table 3), values between 88.76 and 84.80% for WCL and between 88.15 and 84.13% for WCS were estimated under ECw of 0.3 and ~3.6 dS m^{-1}, respectively.

With regard to quality of cauliflower inflorescences, in the winter-spring there were losses due to pinkish spots (only under ECw 0.3 dS m^{-1}), hairy appearance (under ECw of 0.3 and 5.5 dS m^{-1}), and lack of compactness or 'head firmness' (except at ECw of 0.3 dS m^{-1}) (Table 4 and Figure 1A). Despite these records, the losses did not exceed two inflorescences per treatment.

In the spring-summer experiment, the losses were more significant, caused exclusively by inflorescence rot (Table 4 and

Table 4. Percentage (%) of non-marketable cauliflower inflorescences grown under different electrical conductivities of water (ECw) using an NFT hydroponic system for the winter-spring and spring-summer experiments

ECw (dS m^{-1})	Winter-spring				Spring-summer
	Pinkish spots	Hairy appearance	Lack of compactness	Total	Inflorescence rot
0.3 - Control	1.85	1.85	--	3.70	--
1.5	--	--	3.70	3.70	58.00
2.5	--	--	1.85	1.85	61.36
3.5	--	--	3.70	3.70	60.87
4.5	--	--	3.70	3.70	62.74
5.5	--	1.85	1.85	3.70	43.48

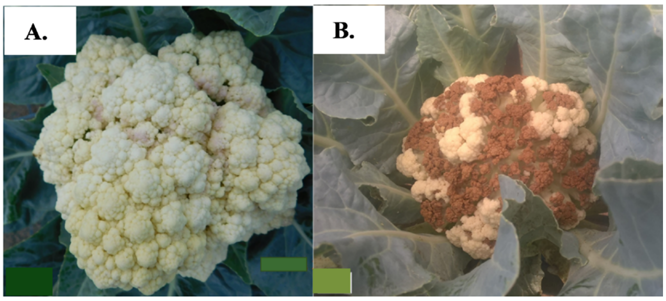

Figure 1. Pinkish spots, hairy appearance, and lack of compactness in winter-spring (A), and rot in spring-summer (B) in the cauliflower inflorescences grown using an NFT hydroponic system

Figure 1B), ranging between 43.48 and 62.74% for ECw values of 5.5 and 4.5 dS m^{-1}, respectively. Without salt stress (ECw 0.3 dS m^{-1}), there was no loss of inflorescence quality. This rot is associated with boron deficiency (Leão Junior & Buso, 2020).

In the present study, the effect of salinity alone does not explain the occurrence of rot in the inflorescences, in the case of the spring-summer experiment. This symptom, as already mentioned, was not observed in the winter-spring experiment. In studies with salinity, reductions in the biomass of cauliflower inflorescences have been recorded, but without any mention of the loss of inflorescence quality (Giuffrida et al., 2017; Costa et al., 2020). Therefore, the present study suggests that the occurrence of rot was probably due to the interaction between the hottest period in which the cultivation was carried out and salinity, which may have restricted the absorption of certain nutrients, such as boron.

The general aspects of the quality of cauliflower inflorescences produced under different ECw values are presented in Figures 2A and B for the winter-spring and spring-summer experiments, respectively.

Regarding the variables of the cauliflower inflorescences (Table 5), in both experiments, there was a significant effect of ECw on all variables evaluated (inflorescence diameter - ID, inflorescence length - IL, ID/IL ratio, inflorescence fresh matter - IFM, inflorescence dry matter - IDM, inflorescence fresh matter yield - IFMY, and water content in inflorescence - WCI). Under the control treatment (ECw 0.3 dS m^{-1}), the estimated means of IFM were 437.76 and 388.01 g for the winter-spring and spring-summer experiments, respectively (Table 5). Despite the lower production in spring-summer (the hottest season of the year, with a mean temperature of 25.8 ± 0.9 °C), these results show that 'SF1758' cauliflower was suitable for cultivation in NFT hydroponics under the climatic conditions of the present study.

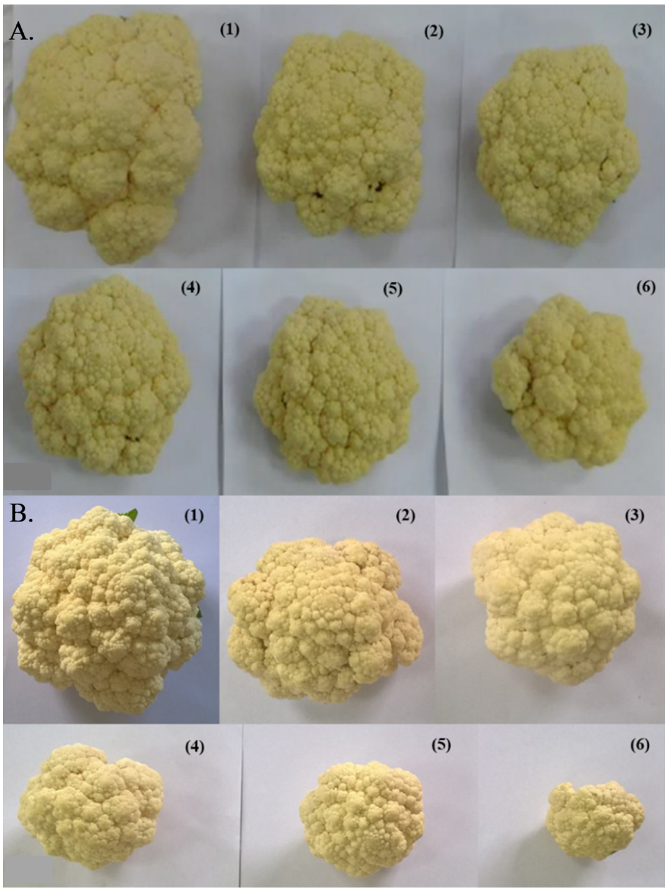

Figure 2. Visual quality of cauliflower inflorescences grown under different electrical conductivities of water (ECw) using an NFT hydroponic system for the winter-spring (A) and spring-summer (B) experiments. (1), (2), (3), (4), (5), and (6) correspond to ECw of 0.3, 1.5, 2.5, 3.5, 4.5, and 5.5 dS m^{-1}, respectively

The same success in cauliflower cultivation was not achieved in the study carried out by Soares et al. (2020) in Recife - Pernambuco, also in Northeast Brazil. In experiments with 'Piracicaba Precoce' and 'Sarah 1169' cauliflower cultivars at different times (not informed) under NFT hydroponics, they reported only the vegetative growth variables of the plants at 49 and 60 DAT, respectively, as there was no formation of inflorescences, even without salt stress (ECw 0.2 dS m^{-1}).

Therefore, the main hypothesis raised by the authors of the present study is that such cultivars were not suitable for the season in which the experiments were carried out by Soares et al. (2020), with mean temperatures of 35 and 33 °C inside the greenhouse. According to Marzouk et al. (2022), when temperatures are high there are irregularities in the formation of inflorescences, or even the absence of formation.

Table 5. Summary of the F-test and fit of regression models for inflorescence diameter (ID, cm), inflorescence length (IL, cm), ID/IL ratio, inflorescence fresh matter (IFM, g), inflorescence dry matter (IDM, g), inflorescence fresh matter yield (IFMY, kg ha^{-1}), and water content in inflorescence (WCI, %) of cauliflower grown under different electrical conductivities of water (ECw) using an NFT hydroponic system in the winter-spring and spring-summer experiments

Variables	p-value	CV (%)	Model or mean	(1)Relation (b/a) × 100	R^2 (%)
			Winter-spring experiment		
ID	≤ 0.001	5.12	ID = 15.636 - 0.633**ECw	4.05	93.55
IL	≤ 0.001	4.77	IL = 10.425 - 0.259**ECw	2.48	81.17
ID/IL ratio	≤ 0.001	3.41	ID/IL ratio = 1.505 - 0.028**ECw	1.83	86.89
IFM	≤ 0.001	10.78	IFM = 448.183 - 34.729**ECw	7.75	87.20
IDM	≤ 0.001(2)	16.57	IDM = mean = 25.75	--	--
IFMY	≤ 0.001	10.78	IFMY = 10004.083 - 775.198**ECw	7.75	87.20
WCI	≤ 0.001(2)	1.25	WCI = mean = 92.41	--	--
			Spring-summer experiment		
ID	≤ 0.001	8.80	ID = 13.450 - 0.975**ECw	7.25	82.80
IL	≤ 0.001	9.07	IL = 10.203 - 0.589**ECw	5.77	85.48
ID/IL ratio	≤ 0.05	7.71	ID/IL ratio = 1.399 - 0.111**ECw + 0.015*ECw^2	--	89.83
IFM	≤ 0.001	12.85	IFM = 424.461 - 125.885**ECw + 14.592**ECw^2	--	98.62
IDM	≤ 0.001	16.58	IDM = 28.818 - 2.792**ECw	9.69	84.29
IFMY	≤ 0.001	12.85	IFMY = 9474.574 - 2809.927**ECw + 325.708**ECw^2	--	98.62
WCI	≤ 0.05(2)	2.25	WCI = mean = 90.34	--	--

CV - Coefficient of variation; **, * - Significant at p ≤ 0.01 and 0.05, respectively, by t-test; (1) - y = a + bx; (2) - There was no satisfactory fit of data to any regression model

In both experiments of the present study, saline water was used to prepare the nutrient solutions and to replace the volume consumed by the plants. As expected, ECsol values increased. Therefore, they caused greater and more significant production losses in the spring-summer experiment (Tables 4 and 5). At the end of the experiment, under different electrical conductivities of water with NaCl (ECw 1.5, 2.5, 3.5, 4.5, and 5.5 dS m^{-1}), the ECsol values, on average, increased approximately 3-fold compared to the initial cultivation condition (Table 1). This considerable increase in ECsol occurred at the expense of the greater water demand of cauliflower during this growing season, with a greater contribution of toxic ions (predominantly Na^+) in the nutrient solution. Therefore, part of these ions was absorbed by the plants, while another significant part was not absorbed, remaining in the solution, thus increasing ECsol. Despite these significant increases in ECsol, the yields of fresh biomass of inflorescences were satisfactory (Figure 2), and a relative yield [RY = (saline treatment/control treatment) × 100] of approximately 60% was recorded under higher salinity in winter-spring. In spring-summer, under ECw values of up to 2.5 dS m^{-1}, RY values were above 50%.

Therefore, in the hottest season of the year, it may be strategic to allocate saline waters only for the preparation of nutrient solutions or to replace the water consumed by plants. Although the cultivation was carried out under different conditions, it is worth mentioning the results of Giuffrida et al. (2017) with 'Conero' cauliflower in pots with sand, in the autumn season in Italy. In that study, the authors observed that there was no significant difference in IFM when the saline solution (ECsol 4.0 dS m^{-1} with NaCl) was applied from transplanting to appearance of inflorescence compared to the control (ECsol 2.0 dS m^{-1} applied throughout the crop cycle).

In the winter-spring experiment, the means for ID were 15.45 and 12.15 cm, and for IL they were 10.35 and 9.00 cm under ECw of 0.3 and 5.5 dS m^{-1}, respectively (Table 5). Lower values were recorded in the spring-summer experiment, around 13.16 and 8.09 cm for ID and 10.03 and 6.96 cm for IL, respectively. As a consequence of the larger surfaces in the winter-spring, there was a greater accumulation of water in the tissues of the cauliflower inflorescences, hence leading to higher IFM production. In both experiments, the increasing levels of ECw did not affect the water status of the inflorescences, with mean values for WCI of 92.41% in the winter-spring and 90.34% in spring-summer (further reinforcing lower IFM production).

For IFM yield, under the control treatment (ECw 0.3 dS m^{-1}) mean values of 9,771.52 and 8,660.91 kg ha^{-1} were estimated for the winter-spring and spring-summer experiments, respectively (Table 5). The spacing used in the experiments was considered adequate for the growth of cauliflower plants, mainly because it does not harm the movement between the hydroponic benches. It was not possible to compare these IFM yields obtained in the present study with others reported in the literature, either under soil or hydroponic cultivation conditions. Firstly, because there are no studies with this same cultivar, and secondly, because comparisons with other cultivars are not justified, as each cultivar has a different growth pattern and harvest period. Therefore, such results are important for comparisons in future studies with this same cultivar.

Regarding the water consumption (WC) of cauliflower, in both experiments, there was a significant effect as a function of increasing ECw values (Table 6). For water use efficiency based on leaves (WUE-LFM or WUE-LDM) or inflorescences (WUE-IFM or WUE-IDM), there was a significant effect only on WUE-LDM in the winter-spring experiment; however, there was no satisfactory fit of any regression model to describe the data. In spring-summer, there was a significant effect of ECw on WUE-LFM, WUE-LDM, and WUE-IFM.

The accumulated WC of cauliflower during the growing cycles, as expected, was higher in the hottest season of the year (spring-summer experiment), with variation between 18.27 and 48.07 L per plant under ECw of 5.5 and 0.3 dS m^{-1}, respectively (Table 6). Even under high salinity (ECw 5.5 dS m^{-1}) and increasing throughout the cultivation, the plants continued to absorb water and nutrients, to the point that water

Table 6. Summary of the F-test and fit of regression models for the water consumption (WC, L per plant), water use efficiency based on leaves (WUE-LFM and WUE-LDM, kg m^{-3}) and inflorescences (WUE-IFM and WUE-IDM, kg m^{-3}) of cauliflower grown under different electrical conductivities of water (ECw) using an NFT hydroponic system for the winter-spring and spring-summer experiments

Variables	p-value	CV (%)	Model or mean	(1)Relation (b/a) × 100	R^2 (%)
			Winter-spring experiment		
WC	≤ 0.001	13.61	WC = 20.010 - 1.203**ECw	6.01	93.62
WUE-LFM	> 0.05	39.93	WUE-LFM = mean = 27.15	--	--
WUE-LDM	≤ 0.05(2)	24.99	WUE-LDM = mean = 2.12	--	--
WUE-IFM	> 0.05	27.76	WUE-IFM = mean = 21.62	--	--
WUE-IDM	> 0.05	34.91	WUE-IDM = mean = 1.65	--	--
			Spring-summer experiment		
WC	≤ 0.001	5.97	WC = 49.791 - 5.731**ECw	11.51	92.70
WUE-LFM	≤ 0.001	14.01	WUE-LFM = 11.609 - 1.081**ECw	9.31	83.38
WUE-LDM	≤ 0.001	18.40	WUE-LDM = 1.418 - 0.222**ECw	15.64	88.15
WUE-IFM	≤ 0.001	13.00	WUE-IFM = 7.972 - 1.349**ECw + 0.239**ECw^2	--	84.91
WUE-IDM	> 0.05	19.10	WUE-IDM = mean = 0.64	--	--

CV - Coefficient of variation; ** - Significant at p ≤ 0.01 by t-test; (1) - y = a + bx; (2) - There was no satisfactory fit of data to any regression model

consumption became comparable to that recorded without salt stress in winter-spring (with estimated WC of 19.65 L per plant; under ECw of 5.5 dS m^{-1} the mean was 13.39 L per plant).

In winter-spring, the variation in water consumption was within the range recorded in the study carried out by Cruz et al. (2018) for 'Piracicaba Precoce' cauliflower (for 49 DAT) in an NFT hydroponic system, i.e., between 14.05 and 23.87 L per plant under ECw of 5.5 and 0.2 dS m^{-1}, respectively, with a flow rate of 1.5 L min^{-1} of nutrient solution application in the hydroponic channels. In the study carried out by Cruz et al. (2021) under the same growing conditions, but at a different time (not informed), water consumption was equal to 30.30 L per plant under 0.12 dS m^{-1} ECw for 'Sarah 1169' cauliflower (for 60 DAT). Therefore, these results reinforce those found in the present study, i.e., large variations in the water consumption of cauliflower plants were recorded according to the season of the year.

In the winter-spring experiment, the reductions in cauliflower leaf and inflorescence biomass yields under different ECw levels were also compensated by the reduction in plant water consumption. Therefore, WUE was kept unchanged under the increasing ECw values, with a mean value for WUE-IFM of 21.62 kg m^{-3}. WUE-LFM, WUE-LDM, and WUE-IDM were also maintained, regardless of the ECw levels, with means shown in Table 6. In the spring-summer experiment, the high water consumption of cauliflower plants led to low WUE-IFM, ranging between 6.07 and 7.80 kg m^{-3} under ECw of 2.82 and 5.5 dS m^{-1}, respectively. WUE-LFM and WUE-LDM decreased by 9.31 and 15.64% for each unit increase in ECw (Table 6).

As mentioned earlier, comparisons with results from other studies should be done with caution, as each cauliflower cultivar has a different growth pattern and harvest period, which can influence WUE-IFM. For example, in the study carried out by Souza et al. (2018) with cauliflower in Brazil in 2015, the WUE-IFM values ranged between 8.88 and 17.33 kg m^{-3} under irrigation depths of 120 and 40% of crop evapotranspiration (without considering effective precipitation), respectively. It is worth mentioning that such studies were carried out under field conditions.

In summary, for some time, hydroponic cultivation was considered an unfeasible production system for conventional small producers due to the high costs for acquiring the necessary equipment for this type of cultivation. In the present study, the results show that in the hydroponic production system it was possible to use waters with high values of electrical conductivity. Therefore, the use of hydroponics can be justified by this advantage; in addition, a smaller volume of water is required.

Conclusions

1. For leaf blade area at inflorescence harvest, reductions per dS m^{-1} increment in water salinity of 7.22 and 6.41% were found in the winter-spring and spring-summer experiments, respectively.

2. The water content in leaves and in the shoot (winter-spring experiment), and cauliflower inflorescences (in both experiments) were not affected by brackish waters (0.3-5.5 dS m^{-1}).

3. The quality losses of cauliflower inflorescences were more pronounced in the spring-summer experiment, varying according to the electrical conductivity of water.

4. It is possible to grow cauliflower hydroponically under electrical conductivity of water of up to 5.5 dS m^{-1}; however, in the hottest seasons these waters should be reserved and used only for the preparation of nutrient solutions or replacement of water consumed by plants.

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