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ORIGINAL ARTICLE

Use of algae extract as an agent to mitigate salt stress in sunflower crop[1]

Uso de extrato de algas como um agente mitigador do estresse salino na cultura de girassol

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HIGHLIGHTS:

- *The electrical conductivity of irrigation water above 1.2 dS m^{-1} reduces sunflower production.*
- *The algae extract attenuates the deleterious effect of salts on sunflowers up to an electrical conductivity of the water of 1.2 dS m^{-1}.*
- *Sunflower production variables were favored by algae extract.*

ABSTRACT: For the use of saline waters in agriculture to be a viable option, solutions must be adopted to mitigate the impacts caused by these waters. In this context, the present study aimed to evaluate the foliar application of algae (*Ascophyllum nodosum*) extract as a strategy to mitigate the deleterious effects of salinity on the production and post-harvest variables of the 'BRS 324' sunflower. The experiment was conducted in a randomized block design with a split-split-plot arrangement, composed of four salinity levels of water (1.2, 3.0, 4.5, and 6.0 dS m^{-1}) and four doses of algae extract (0, 100, 150, and 200% of recommended dose) in two crop cycles, with four blocks. The 100% of the recommended dose (32 mg L^{-1}) of the algae extract positively influenced the 1000-achenes weight (increases of 6.05 and 3.63% for the levels of 1.2 and 3.0 dS m^{-1}, respectively) and the achene yield (increments of 7.07 and 4.59% for the levels of 1.2 and 3.0 dS m^{-1}). The algae extract did not influence the oil and protein content and yield. The increase in salinity levels reduced all variables studied. Algae extract mitigated the deleterious effects of salinity on 1,000-achene weight and yield of achenes at the lowest water salinity level (1.2 dS m^{-1}). The most effective dose of the algae extract to mitigate the negative effects of salinity on the 1,000-achene weight and achene yield was 100% (32 mg L^{-1}) of the recommendation of the extract.

Key words: salinity, *Ascophyllum nodosum*, *Helianthus annuus*

RESUMO: Para que o uso de águas salinas na agricultura seja uma opção viável é necessário que soluções sejam adotadas para atenuar os impactos provocados por essas águas. Nesse sentido, objetivou-se avaliar a aplicação foliar de extrato de algas (*Ascophyllum nodosum*) como estratégia para atenuar os efeitos deletérios da salinidade sobre as variáveis de produção e pós-colheita do girassol 'BRS 324'. O experimento foi conduzido em delineamento de blocos casualizados, com esquema de parcelas sub-sub-divididas, composto por quatro níveis de salinidade da água (1,2; 3,0; 4,5 e 6,0 dS m^{-1}) e quatro doses do extrato de algas (0, 100, 150 e 200% da dose recomendada), em dois ciclos de cultivos, com quatro blocos. A dose de 100% da recomendação (32 mg L^{-1}) do extrato influenciou positivamente o peso de 1.000 aquênios (acréscimos de 6,05 e 3,63% para os níveis de 1,2 e 3,0 dS m^{-1}, respectivamente) e o rendimento de aquênios (incrementos de 7,07 e 4,59% para os níveis de 1,2 e 3,0 dS m^{-1}). O teor de óleo e proteína, rendimento de óleo e proteína não foram significativamente influenciados pelo extrato. Os níveis crescentes de salinidade reduziram todas as variáveis estudadas. O extrato de algas mitigou os efeitos deletérios da salinidade no peso de 1.000 aquênios e na produção de aquênios no nível mais baixo da salinidade da água (1,2 dS m^{-1}). A dose mais eficaz do extrato para mitigar os efeitos negativos da salinidade no peso de 1.000 aquênios e no rendimento de aquênios foi 100% da recomendação do extrato (32 mg L^{-1}).

Palavras-chave: salinidade, *Ascophyllum nodosum*, *Helianthus annuus*

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INTRODUCTION

One of the strategies for using marginal quality water (water with a relatively high salt content) in agriculture is the use of algae extracts. Some studies have demonstrated the potential for using these extracts as attenuators of salt stress (Suganthi & Sujatha, 2014; Fátima et al., 2023). The alga species *Ascophyllum nodosum* is the most studied in agriculture, as several commercial extracts of *A. nodosum* improve plant growth, mitigate some abiotic and biotic stresses, and increase plant defenses by regulating molecular, physiological, and biochemical processes (Fátima et al., 2023).

There is still little information on the agricultural use of algae extract in sunflower cultivation; however, in previous studies, some researchers have obtained increases in the production and yield of this crop. Sírbu et al. (2022) found an 8% increase in sunflower yield when treated with algae-based fertilizer; Karthikeyan & Shanmugam (2015) observed a 51.03% increase in crop yield, while Suganthi & Sujatha (2014) found a 14% increase in the 1,000-achene weight of sunflower treated with algae compared to the control.

Guedes Filho (2015), Amaral et al. (2020), and Rodrigues et al. (2022), among others, refer to the effects of salinity on sunflower; however, studies related to the application of algae extract in crops of these species, associated with the use of saline water for irrigation, are still incipient in Brazil. Considering that the sunflower (*Helianthus annuus* L.) is the third most-produced oilseed crop in the world and the fourth most important crop for vegetable oil production (Pilorgé, 2020), this study aimed to evaluate the foliar application of commercial seaweed extract (*Ascophyllum nodosum*) as a strategy to mitigate the deleterious effects of water salinity on the production and post-harvest variables of 'BRS 324' sunflower.

MATERIAL AND METHODS

The experiments were carried out in an experimental area at the Universidade Federal do Ceará (UFC), Pici Campus, Fortaleza, CE, Brazil, at 3° 44' 45" S, 38° 34' 55"W, and altitude of 19.5 m. The climate of the region, according to Koppen's classification, is Aw-type, and is characterized as tropical rainy, very hot, with rainfall predominating in the summer and autumn seasons (Köppen, 1923). The variation in temperature and average monthly precipitation during the experimental period (first and second cycles) can be observed in Figure 1.

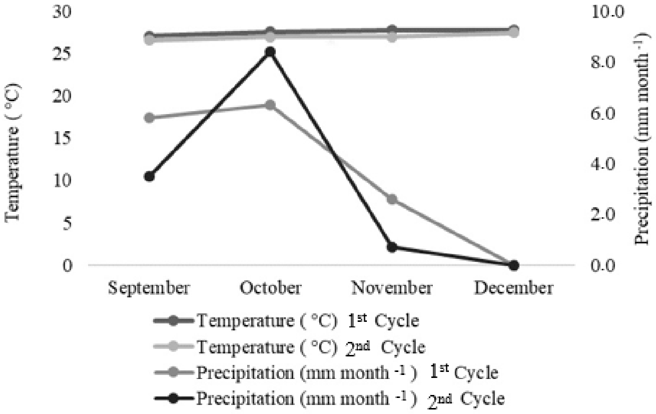

Figure 1. Average temperature and precipitation from September to December of 2016 and 2017

Two sunflower ('BRS 324') crop cycles were evaluated, with the first cycle between September and December 2016 and the second cycle during the same period in 2017. The seeds of the BRS 324 sunflower cultivar were sown in 40 L pots. A 5 cm layer of gravel was placed in each pot to facilitate excess water drainage, and then the pots were filled with soil. The study was conducted under field conditions.

The soil used in the experiments is classified as Entisol Fluvent (USDA, 2014). The samples were collected in the 0-0.20 m layer and then sent for physical and chemical analysis. The soil was discarded at the end of the first cycle, and a new sample was taken (from the same area) for the second cultivation cycle. The results of the analyses are shown in Table 1.

The experiment was carried out in a randomized block design arranged in a split-split plot scheme, consisting of four levels of irrigation water salinity (1.2 - control, 3.0, 4.5, and 6.0 dS m^{-1}) and four doses of seaweed extract (0, 100% (32 mg L^{-1}), 150% (48 mg L^{-1}), and 200% (64 mg L^{-1}) of the recommended dose), with four blocks, in two crop cycles. The experiments comprised 64 experimental units, represented by one pot containing one plant each, totaling 64 plants.

At 15 days after sowing (DAS), irrigations with different salinity levels were started. The levels of electrical conductivity of the irrigation water corresponding to 3.0, 4.5, and 6.0 dS m^{-1} were obtained by adding salts of sodium chloride (NaCl) and calcium chloride ($CaCl_2.2H_2O$), in an equivalent ratio of 7:3, to water from a well located on the site of the experiment. The water at the 1.2 dS m^{-1} level was not artificially salinized. The water was stored in containers with a capacity of 100 L for each salinity level and monitored daily using a portable conductivity meter.

The amount of nutrients applied was calculated based on the soil density (1.45 kg dm^{-3}), the volume of soil in the pot, and the contents of N, P, and K in the soil (Table 1). Boron was also applied. Nutritional supplementation was calculated based on the recommendations of Carvalho et al. (2013) for each crop cycle.

The seaweed extract used was in powder form, completely soluble in water. The extract was applied via foliar spray using

Table 1. Soil chemical attributes for each crop cycle

Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$H^{+} + Al^{3+}$	SB	CEC	P	OM	pH	SB	ESP	ECse
($cmol_c$ kg^{-1})							(mg kg^{-1})	(g kg^{-1})		(%)		(dS m^{-1})
Soil chemical attributes - first cycle												
4.0	2.2	0.14	0.43	1.16	6.8	7.9	63	11.4	7.2	86	2	0.20
Soil chemical attributes - second cycle												
5.0	2.7	0.14	0.52	0.99	8.4	9.3	84	14.2	6.9	90	1	0.20

SB - Sum of bases; CEC - Cation exchange capacity; OM - Organic matter; ESP - Exchangeable sodium percentage; ECse - Electrical conductivity of saturated extract a sprayer weekly. Applications began 20 days after sowing (DAS) and lasted until 70 DAS, totaling eight applications in each crop cycle. The commercial algae extract *Ascophyllum nodosum* used was Alga95®. According to the manufacturer (BioAtlantis), the extract contains macronutrients, chelated micronutrients, more than 60 trace elements, carbohydrates, amino acids, antioxidants, and plant growth stimulants. The product information is shown in (Table 2).

The irrigation management method was based on climatic conditions and conducted according to the daily replacement of the crop's potential evapotranspiration. The reference evapotranspiration (ETo) was estimated based on the evaporation of water from the Class A evaporation pan and the Class A pan coefficient, according to Eq. 1:

$$\mathrm{ETo} = \mathrm{ECA} \times \mathrm{Kt} \tag{1}$$

where:

ETo - reference evapotranspiration (mm);
ECA - evaporation measured in the Class A pan (mm);
Kt - class A pan coefficient (dimensionless).

Potential crop evapotranspiration (ETc) was estimated from the reference evapotranspiration (ETo) multiplied by the crop coefficient (Kc), according to Eq. 2:

$$\mathrm{ETpc} = \mathrm{ETo} \times \mathrm{Kc} \tag{2}$$

where:

ETpc - potential crop evapotranspiration (mm);
ETo - reference evapotranspiration (mm);
Kc - crop coefficient (dimensionless).

The crop coefficients used for the different stages of crop development were proposed by Cavalcante Júnior et al. (2013). The irrigation applied was equivalent to 100% of the crop potential evapotranspiration, and irrigation was conducted manually using a graduated beaker.

The variables evaluated were 1,000-achene weight, achene yield, oil content, oil yield, protein content, and protein yield.

Table 2. Information of the commercial extract of *Ascophyllum nodosum* Alga95® according to the manufacturer

Features	
Appearance	Black micro granular powder
Odor	Marine
Solubility in water	> 99%
pH	9.0 - 10.5
Total solids	92 - 98%
Organic matter	40 - 50%
Inorganic matter	45 - 52%
Density	0.55 - 0.85 kg L^{-1}
Guarantees	
Soluble Potassium Oxide (K_2O)	20%
Total Organic Carbon	26%
Water Soluble Nitrogen	1%
Active ingredients	
Plant hormones: auxin, cytokinin, gibberellin, betaines, abscisic acid, and polyamines. Carbohydrates: alginates, mannitol, laminarin. Amino acids: alanine, glutamic acid, proline, leucine, among other ingredients.	

The 1,000-achene weight was determined following the Rules for Seed Analysis (BRASIL, 2009). The achene yield was obtained by weighing the achenes.

The average achene production was then calculated, and the average achene yield per hectare (kg ha^{-1}) was determined. The achene yield was estimated considering a plant density of 40,000 plants ha^{-1}. The oil and protein content of the achenes were determined according to the methodology proposed by Silva et al. (2004). The oil and protein yields in kg ha^{-1} were estimated based on the values of the achene yield potential.

The data was subjected to analysis of variance and the F test ($p \leq 0.05$) using SISVAR 5.6 software (Ferreira, 2014). Regression equations were adjusted when there was interaction between qualitative (crop cycles) and quantitative factors (salinity levels or doses of seaweed extract). In the presence of interaction between two quantitative factors (salinity levels and algae extract doses), response surfaces associated with mathematical models that best represented the functional relationship between the variables were used. In the case of interaction between the three factors studied (crop cycles, salinity levels, and algae extract doses), the salinity levels and doses of the extract within each crop cycle were split. Response surface graphs and equations were obtained using Table Curve 3D software (Systat, 2023).

RESULTS AND DISCUSSION

The analysis of variance presented in (Table 3) showed that the 1,000-achene weight and the achene yield were significantly influenced by the interaction between crop cycles and water salinity levels and the interaction between water salinity levels and algae extract doses. The other variables were not significantly influenced by the algae extract but were affected by the interaction between crop cycles and salinity levels at $p \leq 0.01$ and $p \leq 0.05$ significance levels.

The interaction between crop cycles and salinity levels for the 1000-achene weight (Figure 2) showed that the values ranged from 24 to 56 g (first cycle) and from 28 to 61 g (second cycle), with reductions of 10.77 and 9.85% per unit increase in the electrical conductivity of the water (ECw) for the first and second cycles, respectively.

Considering that the weight of the achenes is the result of the plant's ability to meet its water and nutritional needs up to the potential limit of each cultivar, it can be inferred that when they are subjected to saline water, there is a reduction in the absorption of water and nutrients, inhibiting the growth and development of plants (Isayenkov & Maathuis, 2019). This compromises nutrient absorption, as well as limiting photosynthesis due to stomatal closure and the effect of salts on chloroplasts, particularly on electronic transport and secondary processes, which reduces plant production (Hameed et al., 2021).

Concerning the data of cultivation cycles in each level of electrical conductivity of the water, it was verified through the means test that there was a significant difference ($p \leq 0.05$) for the 1000-achene weight ($W_{1,000}$). The second cycle demonstrated superiority of 8.92% for values of $W_{1,000}$ concerning the first cycle.

Table 3. Summary of the analysis of variance for 1000-achene weight (W1,000), achene yield (AY), oil content (OC), oil yield (OY), protein content (PC), and protein yield (PY) according to different electrical conductivities of the water combined with doses of algae extract in two cultivation cycles

Source of variation	DF	Mean squares					
		W1,000	AY	OC	OY	PC	PY
Blocks	3	1.00836^{ns}	569.18^{ns}	2.0722^{ns}	766.691^{ns}	0.00104^{ns}	196.378^{ns}
Crop cycles (CC)	1	755.6814^{*}	35211.70^{*}	140.3436^{ns}	1406.5264^{**}	127.5354^{*}	3267.622^{*}
Residue (CC)	3	0.20011	1108.90	0.713919	73620084	0.002	1.348.193
S	3	9385.6112^{*}	34610.49^{*}	3356.116^{**}	1198.3466^{*}	201.406^{*}	6811.69^{*}
CC × S	3	9.09177^{*}	91011.06^{*}	16.1380^{*}	333.7877^{**}	9.869^{*}	91.0282^{*}
Residue (S)	18	0.21082	1167.13	156.172	6601.5	0.000414	2.472.127
SE	3	0.8344^{ns}	1875.76^{ns}	2.83284^{ns}	6632.457^{ns}	0.00455^{ns}	656.040^{ns}
CC × SE	3	0.1744^{ns}	2208.47^{ns}	1.8592^{ns}	750.589^{ns}	0.000487^{ns}	156.197^{ns}
SE × S	9	0.7177^{**}	6286.13^{**}	1.3526^{ns}	843.4591^{ns}	0.00166^{ns}	56.5032^{ns}
CC × SE × S	9	0.1006^{ns}	1544.10^{ns}	1.0853^{ns}	120.4608^{ns}	0.245^{ns}	28.2125^{ns}
Residue (EA)	72	0.4033	1597.55	0.6385	429.81	0.00212	106.434
Total	127	-	-	-	-	-	-
CV - CC (%)	_	1.10	3.00	2.23	7.14	1.3	10.14
CV - S (%)	_	1.24	3.08	3.3	6.76	1.8	13.73
CV - SE (%)	–	1.32	3.60	2.11	5.45	1.3	9.01

S - Salinity; SE - Seaweed extract; DF - Degree of freedom; CV - Coefficient of variation; * - Significant at $p \leq 0.05$; ** - Significant at $p \leq 0.01$; and ^{ns} - Not significant

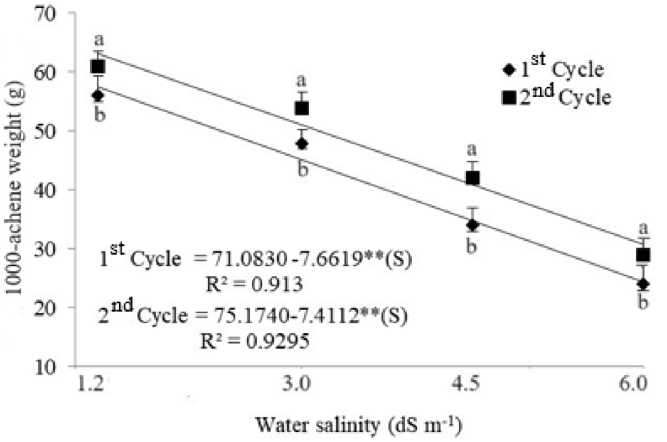

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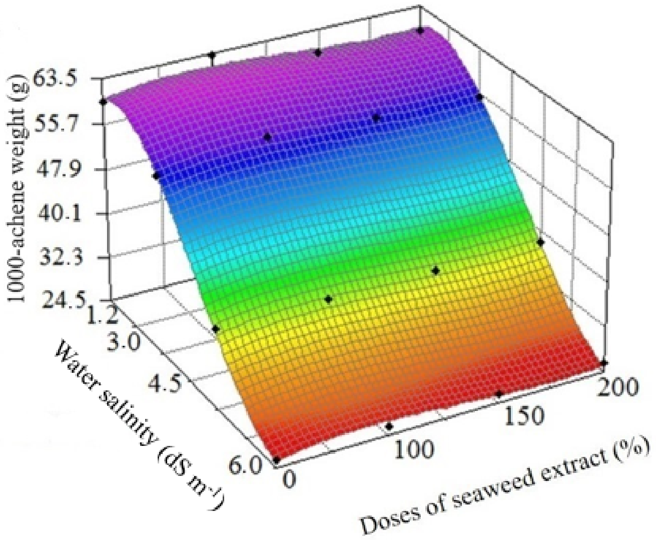
Figure 2. 1000-achene weight (g) according to the water salinity levels for each crop cycle



$W1000 = 24.96 + 49.78^{**}(S) - 25.41^{**}(S)^2 + 3.13^{**}(S)^3 + 11.70^{**}(EA) - 4.82^{**}(EA)^2 + 0.589^{**}(EA)^3$ ($R^2 = 0.9860$)

Figure 3. 1000-achene weight according to the combinations of different water salinity levels and doses of algae extract

As for the interaction between salinity levels and doses of seaweed extract, the response of the variable is shown in Figure 3. The response surface shows that the maximum value (63.1 g) for the 1,000-achene weight came from the treatment with the lowest ECw level (1.2 dS m^{-1}) combined with a dose of 100% (32 mg L^{-1}) of the recommended *A. nodosum* extract.

The increase in salinity levels caused a total reduction of 58.8% (37.1 g) when water of 6.0 dS m^{-1} was used compared to the control. The seaweed extract, on the other hand, led to increases of 6.05% (3.6 g) and 3.63% (2.0 g) at levels of 1.2 and 3.0 dS m^{-1}, respectively, when compared to the control (absence of extract). It should be noted that the higher ECw levels (4.5 and 6.0 dS m^{-1}) inhibited the effects of the seaweed extract. The reduction in production in plants grown under salt stress may be due to a delay in carbon assimilation, associated with osmotic effects and the presence of Na^+ and Cl^- above normal levels, causing disturbances in essential crop processes (Isayenkov & Maathuis, 2019).

Destorani et al. (2022), in a study on sunflower production, irrigated with saline water, found a reduction of 8.3 and 19.3% in the 1,000-achene weight when using the higher levels of salinity (4.0 and 6.0 dS m^{-1}, respectively) compared to the control. As for the extract factor, Suganthi & Sujatha (2014) found an increase of 14% (5.54 g) in the 1,000-achene weight of sunflower plants treated with algae compared to the control. Osman & Salem (2011) point out that seaweed extracts provide better absorption of nutrients by plants, thus contributing to an increase in crop production and yield. It is important to note that potassium is present in the composition of the algae-based product, and this element directly influences the yield potential of the sunflower crop. According to Carvalho et al. (2013), for the BRS 324 cultivar, the expected range for the 1,000-achene weight is between 50 and 65 g, and part of the values obtained in this study fall within this range.

When it came to the interaction between crop cycles and water salinity levels for achene yield (Figure 4), there was a reduction as salinity levels increased. The estimated yield ranged from 650 to 1,344 kg ha^{-1} and from 900 to 1,630 kg ha^{-1} for the first and second cycles, respectively, highlighting that

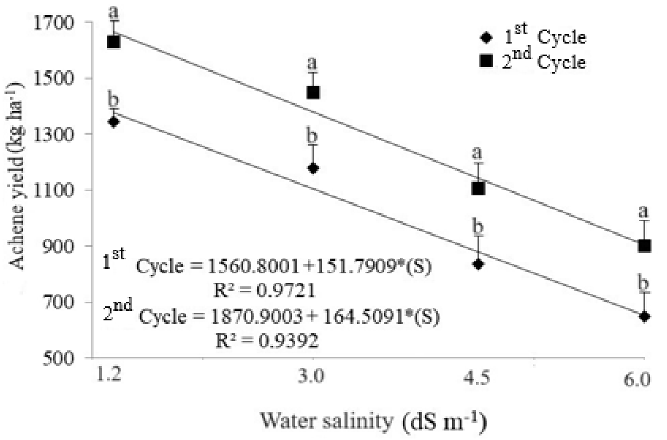


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Figure 4. Achene yield as a function of water salinity levels for each cultivation cycle of sunflower crop

the highest values were obtained using the lowest ECw water (1.2 dS m^{-1}) in both cycles.

The increase in salts in the irrigation water caused decreases of 9.72 and 8.79% per unit increase in ECw for the first and second cycles, respectively. The reduction in achene yield is due to the total energy potential of the water in the soil becoming increasingly negative due to the increase in salinity, making it more difficult for the plant to absorb water despite its availability in the soil (Ayers & Westcot, 1999).

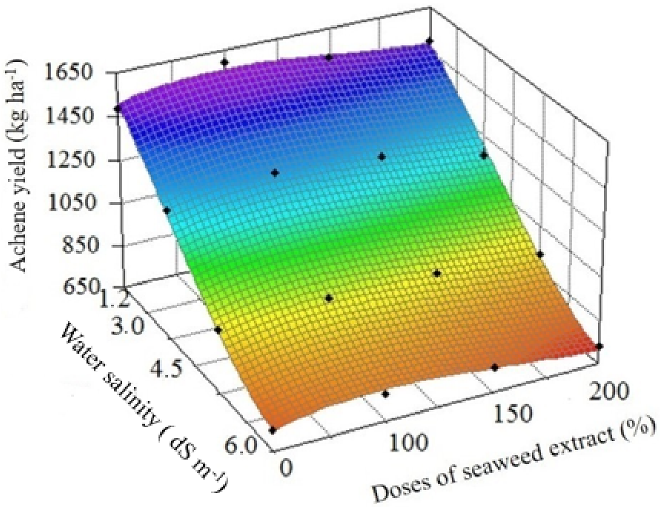
Ceccoli et al. (2022), working with sunflower hybrids, observed that salinity caused a 51.4% decrease in achene yield, considering all genotypes. The authors mentioned above used 130 mM NaCl, equivalent to 13 dS m^{-1}. Similar results for the sunflower crop were also found by Amaral et al. (2020), who found that an increase in ECw (3.0 dS m^{-1}) resulted in a 20.88% decrease in achene yield.

The achene yield also showed a significant difference ($p \leq 0.05$) between the cultivation cycles for each water salinity level, with the second cycle showing a superiority of 21.28%. It is important to mention that in this cycle, inflorescences with larger diameters were observed, showing a positive correlation between inflorescence diameter and achene yield (Pivetta et al., 2012).

Concerning the interaction between water salinity levels and doses of algae extract, Figure 5 shows the functional relationship between the factors mentioned through the response surface.

The highest estimated yield (1,590 kg ha^{-1}) was obtained using water of 1.2 dS m^{-1} (lowest ECw level) associated with a dose of 100% (32 mg L^{-1}) of the extract's recommendation. Sunflower yield responded negatively to the increase in salt levels, showing a reduction of 53.84% (856 kg ha^{-1}) when using the water with the highest salinity (6.0 dS m^{-1}). The algae extract had a positive influence on the variable; it was observed that the 100% (32 mg L^{-1}) dose promoted increases of 7.07% (105 kg ha^{-1}) and 4.59% (57 kg ha^{-1}) in the levels of water salinity 1.2 and 3.0 dS m^{-1}, respectively.

As for the salinity factor, the stress caused by excess ions compromises the photosynthetic system and reduces transpiration, gas exchange, and stomatal conductance, harming crop yield and justifying the reduction in achene yield as a result of increased salinity levels (Pan et al., 2021).



Achene yield = 1426.7 - 13.64**(S) - 138.81**$(S)^2$ + 21.58**$(S)^3$ + 317.37**(EA) - 116.87**$(EA)^2$ + 12.25**$(EA)^3$ ($R^2 = 0.9890$)

Figure 5. Achene yield as a function of combinations of water salinity levels and doses of seaweed extract

Karthikeyan & Shanmugam (2015), in a study on applying algae-based biostimulants to sunflower crops, noted a 51.03% increase in crop yield compared to the control treatment. Similarly, Sîrbu et al. (2022) found an 8% increase in sunflower yield when treated with algae-based fertilizer.

The increase in achene yield may be related to the promotion of achene development, which is caused by the greater availability of cytokinin through the use of algae extract since this hormone is related to the partitioning and mobilization of assimilates directed mainly to these drains when the plant is in the reproductive phase (Carvalho, 2013). In general, although the algae extract had a positive effect on the 1,000-achene weight (W1,000) and achene yield (AY), it is important to note that the most severe effects of salinity inhibited the effects of the extract at the highest ECw levels (4.5 and 6.0 dS m^{-1}).

As for the oil content (OC), it ranged from 42.8 to 46.1% and from 44.0 to 47.2% for the first and second cycles, respectively. The highest values came from the treatments with the lowest ECw (1.2 dS m^{-1}) for both crop cycles (Figure 6A).

Noreen & Ashraf (2010), in a study on the effects of salt (NaCl) on the composition of sunflower oil, noted a reduction in content due to salinity. The authors point out that the oil quality in the achenes is associated with the composition of the fatty acids, especially oleic, linoleic, and linolenic acids.

Flagella et al. (2004) found that the composition of fatty acids is greatly affected by salinity. Under saline conditions, the authors observed that oleic acid increased and linoleic acid decreased progressively with the increase in water salinity. This was related to the salt-induced inhibition of the oleate desaturase enzyme, which catalyzes the conversion reaction of oleic acid into linoleic acid.

Oil yield (OY) varied from 274.76 to 584.33 kg ha^{-1} in the first cycle and 351.45 to 671.02 kg ha^{-1} in the second cycle. The higher values, 584.33 and 671.02 kg ha^{-1} were obtained in the treatments with the lowest ECw (1.2 dS m^{-1}) for the first and second cycles, respectively (Figure 6B). The increased salt concentration in the irrigation water resulted in linear

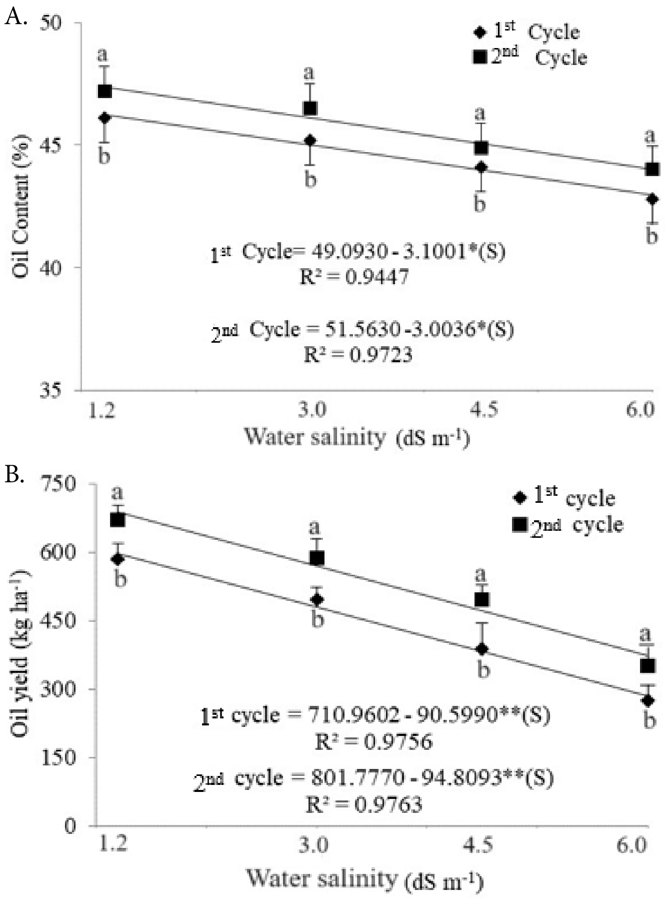


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Figure 6. Oil content (A) and oil yield (B) as a function of water salinity levels for each crop cycle

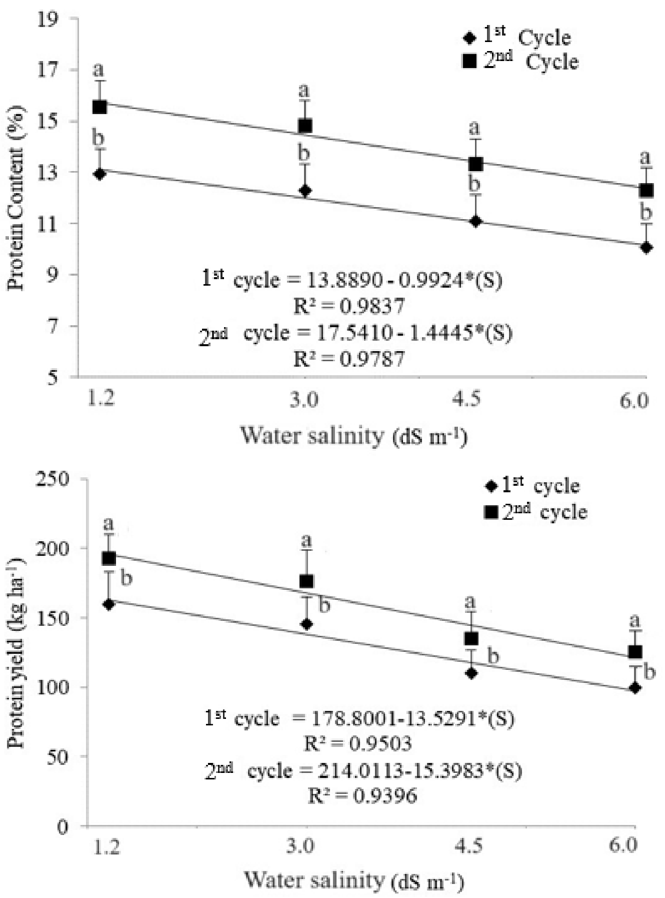

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Figure 7. Protein content (A) and protein yield (B) as a function of water salinity levels (dS m^{-1}) for each crop cycle

decreases in the variable. In the first cycle, there was a reduction of 52.98% (309.57 kg ha^{-1}), and in the second cycle, there was a decrease of 47.63% (319.57 kg ha^{-1}).

These reductions were observed when comparing the treatments with the highest (6.0 dS m^{-1}) and lowest (1.2 dS m^{-1}) salt levels. Guedes Filho et al. (2015) noted that the salinity of irrigation water also linearly reduced the oil yield of the achenes, as there was a 12.5% decrease when comparing the levels of 0.15 to 4.5 dS m^{-1}.

There was also a significant difference ($p \leq 0.05$) concerning the cultivation cycles at each water salinity level for oil content and oil yield. The second cycle showed a superiority of 2.47 and 14.80%, respectively. The oil yield generally showed the same trend as the achene yield, with the highest values obtained in the second growing cycle. Silva et al. (2007) also observed a positive correlation between these variables. The authors found that the most crucial factor for oil yield in sunflower cultivation, apart from the inherent content of the achene, is the achene yield.

Concerning the interaction between salinity levels and crop cycles for protein content (Figure 7A), in the first crop cycle, this variable ranged from 10 to 12.92%, while in the second cycle, the variation was from 12.2 to 15.55%. The higher values were obtained in the plants irrigated with the lowest saline level (1.2 dS m^{-1}). With the increase in salt concentration in the irrigation water, there were decreases of 7.14 and 8.23% per unit increase in ECw for the first and second cycles, respectively. According to Neumann et al. (2009), sunflower's average crude protein concentration is generally around 12%.

Similar results were found by Dawood et al. (2017), who, when assessing the quality and yield of sunflower plants irrigated with saline water, found a 3.44% decrease in protein content with the increase in salts compared to the control. The reduction in protein content due to salinity may be related to disturbances in nitrogen metabolism, inhibition or reduction of nitrate absorption, availability of amino acids, and denaturation of enzymes in the synthesis of amino acids and proteins (El-Mashad & Mohamed, 2012).

As for protein yield, Figure 7B shows the response of this variable according to the salinity levels for each crop cycle. The values for the first cycle ranged from 99.78 to 160.1 kg ha^{-1}, while for the second cycle, the values ranged from 125.02 to 193.03 kg ha^{-1}. The protein yield decreased linearly as the salt levels increased, with the highest values (160.1 kg ha^{-1} - first cycle and 193.03 kg h^{-1} - second cycle) coming from the treatments with the lowest ECw level (1.2 dS m^{-1}). A decrease in protein yield due to increased water salinity levels may be related to nutritional imbalances caused by excess salts in nutrient absorption, given that salinity reduces ionic activity in solution and alters nutrient absorption processes by plants, especially nitrogen, resulting in a decline in yield (Cruz et al., 2018).

There was also a significant difference ($p \leq 0.05$) between the cultivation cycles for each water salinity level for protein content and protein yield. The second cycle was higher by 20.35 and 20.56%, respectively. The second cultivation cycle showed superiority for all variables analyzed. This fact can be justified by the initial fertility of the soil in that cycle, considering that the initial levels of phosphorus, potassium, and organic matter were higher (Table 1).

In this way, there may have been a greater availability of nutrients to the plant, thus influencing yield and post-harvest variables, since N, associated with K, is the biggest nutritional limit to sunflower yield, in addition to being a key element in protein synthesis (Blamey et al., 1997). It is important to highlight that the second cycle presented the highest achene yield, considering that achene yield directly and positively affects protein yield (Hladni et al., 2015).

Another factor that may have influenced the superiority of the second cycle is temperature since the temperatures recorded in the first cultivation cycle were higher (Figure 1), which may have caused greater evaporation and consequently caused a greater concentration of salts in the soil, damaging the crop (Silva et al., 2019).

CONCLUSIONS

1. The seaweed extract mitigated the deleterious effects of salinity on the 1,000-achene weight and achene yield at the lowest level of electrical conductivity of the water (1.2 dS m^{-1}), and its effect was inhibited at higher water salinity levels.

2. The most effective dose of the algae extract to mitigate the negative effects of salinity on the 1,000-achene weight and achene yield was 100% (32 mg L^{-1}) of the recommendation for the *A. nodosum* extract.

3. The increasing salinity levels in the irrigation water negatively influenced all the yield and post-harvest variables of the 'BRS 324' sunflower.

4. The second crop cycle showed superiority for all sunflower yield and post-harvest variables.

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