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Effect of *Ascophyllum nodosum* Seaweed Extract on Growth and Elemental Nutrient Composition of Safflower (*Carthamus tinctorius* L.) under Salt Stress

Nursel Çöl Keskin[1,a,*], Münüre Tanur Erkoyuncu[1,b]

[1]*Selçuk University, Faculty of Agriculture, Department of Field Crops, 42130, Konya, Türkiye*
[*]*Corresponding author*

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ABSTRACT

Biostimulants have been used in recent years as innovative approaches to stabilize or increase the yield and quality of plants under abiotic stress conditions. Seaweeds, one of the biostimulants, have been used in many cultivated plants and favorable results have been obtained in terms of yield, quality and elemental composition of plant nutrients. Although it is known that safflower plant is sensitive to salt during emergence and germination period, salt and seaweed applications have not been investigated on this plant before. It was aimed to examine the tolerance mechanisms of seaweed applications in safflower plant under salinity stress in terms of some morphological parameters and elemental composition of plant nutrients. The five different doses of salt treatment (0 mM NaCl-distilled water as control, 50 mM, 100 mM, 150 mM, 200 mM) and four different doses of *Ascophyllum nodosum* seaweed extract (0 g L^{-1} - distilled water as control, 2 g L^{-1}, 4 g L^{-1}, 6 g L^{-1}) were used as the treatment groups in this study conducted in the climate chamber under controlled conditions. When the figures obtained from safflower plants treated with seaweed in terms of growth parameters were evaluated; root and shoot length, fresh root and shoot weights, dry root and shoot weights generally increased with increasing doses, while relative water content decreased. As salinity stress increased, decreases were generally recorded in all growth parameters obtained. Improved elemental composition of plant nutrients both shoot and root were also observed with seaweed extract applications. In particular, K and Mg in shoot, Ca, Cu and Mg in root increased with increasing seaweed applications. The findings obtained from the study show that seaweed is a promising agricultural application on growth parameters and elemental composition of plant nutrients and reduces the negative effects of salinity stress on safflower plant.

[a] nurselcol@selcuk.edu.tr https://orcid.org/0000-0002-0089-8442 | [b] mtanur@selcuk.edu.tr https://orcid.org/0000-0001-5004-4771

Introduction

Abiotic stress is nowadays a serious problem for plant growth and yield. Abiotic stresses such as drought, salinity and extreme temperatures cause major yield losses on a global scale. Photosynthesis is one of the physiological processes in plants that are greatly affected by these stresses. The decrease in photosynthetic capacity of plants due to these stresses is directly related to the decrease in yield (Singh and Thakur,2018).

Salinity affects plant growth and development in two ways. Firstly, it reduces the water potential of the soil, limiting water uptake and causing osmotic stress. Secondly, it causes excessive uptake of ions, mainly Na^+ and Cl^-, and consequently interferes with various metabolic processes. Plant responses to osmotic and ionic components of salt stress are complex and involve many gene networks and metabolic processes. Such responses mainly depend on a natural salt tolerance of the plant, the severity of salt stress (salt concentration in the soil solution) and the duration of salt exposure of plant roots (Abogadallah, 2010).

More than 1.100 million ha of soils in the world are affected by salinity and sodicity. Of these, 60% are saline, 26 % sodic and the remaining 14% saline-sodic. Salt-affected soils are found on all continents. The most affected regions are the Middle East, Australia, North Africa and Eurasia. Since most salt-affected soils occur in arid or semi-arid climates, food production in these regions requires irrigation. Some estimates show that 20% to 50% of irrigated soils are affected by salt (Anonymous, 2024). A salinity problem is encountered in 1.7% (1.518.746 ha) of the soils and 3.8% (837.405 ha) of the agricultural lands in Türkiye (Karaoğlu and Yalçın, 2018). On the other hand, another author (Demirkaya 2014) predicts that if not prevented, 50% of the world's agriculture may experience salinity problems by 2050.

Safflower seeds contain 30-50% oil and 77% linoleic acid in its, which increases its value in terms of human nutrition (İnan, 2014). The safflower has a great importance in meeting the vegetable oil deficit of Türkiye and has the potential to be an important oilseed plant especially for regions where dry agricultural areas are common. Considering that most of the soils in Türkiye have salinity, alkalinity and drainage problems, it is of great importance to emphasize the salt tolerance of safflower varieties and lines (Arslan et al., 2012).

The safflower plant is rated moderately tolerant to salinity as well as being resistant to drought and cold. Salinity decreases and delays germination especially in safflower and thus causes a decrease in yield (Weiss, 1971; Kaya et al., 2003). However, in safflower plant, there are sensitive ecotypes as well as salt tolerant ecotypes (Hussain et al., 2016). In the studies on safflower and salinity, safflower plant grown under salt stress inhibits plant growth by suppressing the relative water content, osmotic and turgor potential in the leaves and decreasing the fresh weight (Jabeen and Ahmad, 2012). It is also known that safflower is more sensitive to salinity tolerance during germination than in later growth stages. The transpiration rate of safflower plant affected by salinity during emergence and germination decreases, the number of stomata in the leaf decreases as the leaf cell structure will change and seed yield is negatively affected. In safflower, the degree of salinity sensitivity varies according to the variety, climate and soil structure, irrigation status and developmental stages of the plant (Kaffka and Kearney, 1998).

Biostimulants offer a potentially novel approach for the regulation of physiological processes in plants to stimulate growth, reduce stress-induced limitations and increase yield, and have recently been widely used. Seaweed extracts, one of the biostimulants, increase the tolerance of cultivated plants to salinity stress. At the same time, seaweed extracts contain a number of bioactive compounds, signaling molecules, some vitamins and phytohormones, as well as many mineral and organic plant nutrients that are of great benefit to plants (Herve and Rouillier, 1977; Yakhin et al., 2017; Hernández-Herrera et al., 2022). There are 9000 species of seaweeds divided into three main groups such as *Phaeophyta*, *Rhodophyta* and *Chlorophyta*, which are brown, red and green in colour respectively, and only brown coloured seaweeds contain 2000 species (Khan et al., 2009). *Ascophyllum nodosum* is among the abundant brown seaweed species in the cold temperate North Atlantic Ocean, which is widely used in agriculture (Keser et al., 2005). Many studies have been carried out on seaweed and salinity and positive results have been obtained. In *Arabidopsis thaliana* plant, the biomass of *Ascophyllum nodosum* seaweed extract under saline conditions increased by approximately 50% compared to the control under 100 mM and 150 mM salinity conditions (Jithesh et al., 2019). In tomato plants, it increased the uptake of mineral substances, antioxidants and essential amino acids (Di Stasio et al., 2018). In winter rapeseed, it was reported that seaweed extract increased root and shoot growth, had positive effects on plant development and increased N, S, C uptake (Jannin et al., 2013). In soybean plant, it was found that brown seaweed applied as priming to seeds and spraying to leaves to prolong the viability of seeds increased the emergence rate, leaf area index, stomatal conductance, oil and seed yield (Arab et al., 2022). Positive results were also obtained in different plants grown under salinity stress according to the type, dose and application method of seaweed extract (Ramarajan et al., 2013; Hussein et al., 2021; Chanthini et al., 2022). However, no study has been found to investigate the effects of seaweed extract applications under salt stress in safflower plant. In this study, it was aimed to examine the effects of *Ascophyllum nodosum* seaweed extract applications in safflower plants grown under different salt stress levels in terms of growth characteristics and elemental composition of plant nutrients in shoot and root.

Materials and Methods

Seaweed Extract and Salt Application

In this study, five different doses of salt treatment (0 mM NaCl - distilled water as control, 50 mM, 100 mM, 150 mM, 200 mM) and four different doses of brown seaweed extract (*Ascophyllum nodosum*, Maxicrop, UK) (0 g L^{-1}-distilled water as control, 2 g L^{-1}, 4 g L^{-1}, 6 g L^{-1}) were used as the treatment groups. High-purity analytical-grade NaCl was used to induce salt stress.

Plant Material, Growing Conditions and Experimental Design

The Dinçer variety was used as safflower variety and the seeds were obtained from Utek Seed Company in Konya. The study was conducted under controlled conditions in the climate chamber of the Department of Field Crops using a Split-Plot Randomized Design with four replications. Before sowing, the seeds were surface sterilized by immersion in 5% (w/v) sodium hypochlorite for 3 minutes to prevent fungal growth and then rinsed three times with sterile distilled water (Hadjadj et al., 2023). The surface-sterilized seeds were sown in 3 L pots containing equal volumes (1:1:1) of peat:perlite:sand, with 6 seeds in each pot, and watered twice a week with 100 ml of distilled water. After sowing, the pots were placed in a controlled climate chamber (25±2°C temperature, 65% humidity, 16 h light/8 h dark photoperiod and 200 $\mu mol m^{-2} s^{-1}$ light intensity). At the end of emergence, the plants were thinned out so that 4 plants remained in each pot. After emergence, considering water retention capacity, plants were watered twice a week with ½ diluted Hoagland's nutrient solution (Hoagland and Arnon, 1950) at a rate of 150 ml per pot until the early seedling stage (4 weeks). Salt applications began 21 days after germination, once all seedlings were uniformly developed. To prevent osmotic stress, salt was applied in equal amounts every other day, and adjusted to a total of 200 ml per pot per week, considering soil moisture and field capacity. Additionally, to prevent salt accumulation in the plant roots, the plants were irrigated once a week with 100 ml of distilled water (Hosseini et al., 2010; Karray et al., 2011). One week after the initiation of salt stress, different concentrations of seaweed extract (*Ascophyllum nodosum*) were dissolved in distilled water and sprayed onto the leaves of the plants three times a week, with 200 ml applied per pot at each spraying. No treatment was applied to the control plants. The combined salt and seaweed applications continued for three weeks, and on the 55th day, when morphological and physiological issues (chlorosis, necrosis, and growth retardation) became evident, the plants were harvested for measurement and analysis.

Analyzed All Parameters

In the study, root length (cm), shoot length (cm), root fresh weight (g), shoot fresh weight (g), root dry weight (g), shoot dry weight (g), relative water content (%) and elemental composition of plant nutrients of root and shoot parts were investigated.

Growth Parameters

Fresh weights of the plant samples separated into shoots and roots were determined, then dried in an oven at 70°C for 48 hours and dry weights were calculated.

Relative Water Content (RWC)

In order to determine the relative water content, 2 samples were taken from each pot and their fresh weights were weighed and recorded. The plant samples were kept in pure water in petri dishes for 6 hours to reach turgor state and their turgor weights were recorded. After the plant samples were dried in an oven at 70 °C for 72 hours, their dry weights were determined and the relative water content of the leaf samples of each group was calculated as % according to the equation 1 (Barrs, 1968).

$$\text{RWC}\ (\%) = \frac{(\text{Fresh Weight} - \text{Dry Weight})}{(\text{Turgid Weight} - \text{Dry Weight})} \times 100 \qquad (1)$$

Determination Of Elemental Composition of Plant Nutrients

Dried plant material was weighed (0.2 mg) and placed in tubes. To each tube, 5 ml of nitric acid (HNO_3) and 2 ml of hydrogen peroxide (H_2O_2) were added. The digestion process was carried out in a microwave oven. Once the material was digested, it was transferred to 25 ml glass tubes, and the sample volume was adjusted to 25 ml with pure water. Subsequently, the obtained solution was filtered. Each sample was transferred to a tube and analyzed using ICP-AES, which is capable of simultaneously analyzing 11 different elements 'B, Ca, Cu, Fe, K, Mg, Mn, Na, P, S and Zn' (Lindsay and Norvell, 1978).

Statistical Analysis of Results

The data obtained from the research were subjected to analysis of variance using JMP 11 software (JMP Version 11, SAS Institute Inc., Cary, NC, 1989–2021), with the differences between the averages grouped using the "LSD Multiple Comparison Test" feature in JMP. Additionally, correlation and principal coordinate analyses were performed using the R programming environment.

Results and Discussion

Effects of the SE* and Salinity Treatments *on the Growth Parameters of Safflower Plants

The mean values and groupings of different doses of seaweed (SE) and salt treatments on growth parameters of safflower are shown in Table 1. According to this table, root length, shoot length, root fresh and dry weights, shoot fresh and dry weights, shoot fresh and dry weights and relative water content parameters were found to be statistically significant at 1% significance level in terms of salt and seaweed doses and their interactions.

The effect of different doses of NaCl on root length was classified in group (a) with 11.80 cm at 50 mM, and group (c), with 9.78 cm at 200 mM dose. According to the doses of seaweed extract, the highest root length was measured at 6 g L^{-1} and 2 g L^{-1} doses with 11.07 cm and 11.03 cm, respectively, while the lowest root length was determined in the control group at 10.35 cm. Regarding salt x seaweed interactions, 50 mMx 2 g L^{-1} treatment was in the (a) group with 12.87 cm, and 200 mM x 0 g L^{-1} treatment was in the (g) group. As for shoot length, the effects of salinity varied: the 200 mM, control, and 100 mM doses (36.65 cm, 36.49 cm, and 35.68 cm, respectively) were grouped together in group (a). Among the salt treatments, 150 mM and 50 mM doses (33.48 cm, 32.95 cm, respectively) recorded the lowest shoot length and represented group (b). In the seaweed treatments, the longest shoot length was 36.60 cm at 6 g L^{-1} dose and the shortest shoot length was 33.94 cm at 2 g L^{-1} dose. Analyzing the interactions, the highest value was recorded from 200 mMx4 g L^{-1} treatment with 41.75 cm, while the lowest value was measured from 50 mMx4 g L^{-1} treatment with 29.57 cm. Overall, as salt doses increased, root and shoot lengths decreased, although there were fluctuations and exceptions, as shown in Figure 1. It can be observed that the application of seaweed has generally led to an increase in both root and shoot lengths.

Root and shoot fresh weights showed the same responses under salt stress. Accordingly, both 50 mM and control salt treatments represented group (a) (root fresh weight 0.78 g $plant^{-1}$; shoot fresh weight 5.07, 4. 88 g $plant^{-1}$), weights decreased as the doses increased and were classified in group (b) (RFW 0.72 g $plant^{-1}$ '150 mM', 0.60 g $plant^{-1}$ '200 mM', 0.57 g $plant^{-1}$'100 mM'; SFW 4.08 g '150 mM', 3.98 g '100 mM', 3.60 g '200 mM'). Root and shoot fresh weights were irregular according to seaweed treatments, the highest values were recorded at 2 g L^{-1} dose (0.81, 5.01 g $plant^{-1}$, respectively). In the saltxseaweed interaction, the values obtained from 50 mMx2 g L^{-1} treatment gave the best results in both root and shoot fresh weights (1.08 g, 6.47 g, respectively). It can be stated that the effects of salinity on root and shoot dry weights were inversely proportional. As the salt concentration increased, the values partially decreased except for the control group. The highest values were found in root dry weight at 50 mM dose with 0.19 g and in shoot dry weight at 50 mM (1.23 g) and control (1.18 g) groups. As for the effect of seaweed treatments, it can be said that root and shoot dry weights increased as the doses increased. When the interactions were examined, the highest value of both parameters was weighed in 50 mMxcontrol treatment (0.25 g, 1.41 g, respectively). The lowest value of root dry weight was obtained from 100 mMx control treatment with 0.08 g, while shoot dry weight was obtained from 150 mMx control and 100 mMx control treatments with 0.85 g and 0.70 g, respectively. Overall, it can be said that seaweed reduces the effects of salinity (Table 1).

When root and shoot lengths of *Vigna sinensis*, *Zea mays* plants grown under salt stress and primed with different seaweed extracts were examined, positive effects of different types of seaweed priming applications were determined (Hussein et al., 2021).

Table 1. Effects of NaCl and Seaweed Extract Concentrations on Growth Parameters of Safflower.

Applications		Parameters						
NaCl (mM)	SE ($g L^{-1}$)	RL (cm)	SL (cm)	RFW (gr/plant)	RDW (gr/plant)	SFW (gr/plant)	SDW (gr/plant)	RWC (%)
Control (S0)	0	10.86 c-e[1]	36.45 c-e	0.59 e-ı	0.12 f-h	4.97 b-d	1.02 e-g	109.51 a
	2	10.72 c-e	35.38 de	0.90 a-c	0.21 bc	4.67 b-f	1.05 e-g	60.59 c
	4	10.47 d-f	35.35 de	0.65 e-ı	0.16 de	4.95 b-d	1.33 a-c	83.99 b
	6	10.89 c-e	38.78 a-c	0.96 ab	0.18 cd	4.93 b-e	1.33 a-c	78.39 b
S0 average		10.74b	36.49 a	0.78 a	0.16 b	4.88 a	1.18 a	83.12 a
50 (S1)	0	11.48 b-d	34.17 d-g	0.71 c-g	0.25 a	5.53 ab	1.41 a	83.33 b
	2	12.87 a	33.46 e-g	1.08 a	0.17 d	6.47 a	1.35 ab	59.47 cd
	4	10.54 d-f	29.57 h	0.60 e-ı	0.13 e-g	3.71 d-h	1.08 c-g	51.92 d-g
	6	12.31 ab	34.60 d-f	0.75 c-f	0.22 ab	4.59 b-g	1.10 b-g	44.45 gh
S1 average		11.80 a	32.95 b	0.78 a	0.19 a	5.07 a	1.23 a	59.79 b
100(S2)	0	10.36 d-f	34.89 de	0.46 ı	0.08 ı	3.44 f-h	0.70 h	53.82 c-f
	2	10.68 c-e	35.62 c-e	0.67 d-h	0.10 g-ı	4.88 b-e	0.92 e-h	52.69 d-f
	4	10.06 e-g	37.21 b-d	0.55 g-ı	0.09 hı	3.87 c-h	1.06 d-g	56.27 cd
	6	10.88 c-e	35.02 de	0.61 e-ı	0.11 g-ı	3.72 d-h	1.09 b-g	41.38 hı
S2 average		10.50b	35.68a	0.57b	0.09 d	3.98 b	0.94 b	51.04 c
150(S3)	0	10.30 d-f	31.50 f-h	0.56 f-ı	0.09 hı	3.81 c-h	0.85 h	53.26 c-f
	2	10.78 c-e	34.40 d-f	0.73 c-g	0.13 e-g	5.11 bc	1.16 e-h	46.15 f-h
	4	10.32 d-f	33.43 e-g	0.85 b-d	0.12f 1-h	4.13 c-g	1.08 d-g	52.43 d-f
	6	12.01 a-c	34.60 d-f	0.74 c-g	0.15 d-f	3.28 gh	0.87 b-g	46.90 f-h
S3 average		10.85 b	33.48 b	0.72 a	0.12 c	4.08 b	0.99 b	49.68 c
200(S4)	0	8.77 g	34.02 d-g	0.49 hı	0.11 g-ı	2.67 h	0.68 gh	55.38 c-e
	2	10.08 e-g	30.84 gh	0.69 d-g	0.13 e-g	3.94 c-h	0.84 a-e	48.06 e-h
	4	11.00 b-e	41.75 a	0.76 c-e	0.15 d-f	4.19 b-g	1.13 c-g	34.30 ı
	6	9.25 fg	40.00 ab	0.48 hı	0.11 g-ı	3.59 e-h	1.32 f-h	51.93 d-g
S4 average		9.78 c	36.65 a	0.60 b	0.12 c	3.60 b	0.99 b	47.42 c
SE average	0	10.35 b	34.21 bc	0.56 c	0.13 b	4.08 b	0.93 b	71.06 a
	2	11.03 a	33.94 c	0.81 a	0.15 a	5.01 a	1.06 a	53.39 b
	4	10.48 ab	35.46 ab	0.68 b	0.13 b	4.17 b	1.14 a	55.78 b
	6	11.07 a	36.60 a	0.71 b	0.15 a	4.02 b	1.14 a	52.61 b
LSD (%)		S:0.71** SE:0.60** SxSE:1.34**	S:1.79** SE:1.50** SxSE:3.36**	S:0.11** SE:0.08** SxSE:0.19**	S:0.02** SE:0.01** SxSE:0.03**	S:0.67** SE:0.61** SxSE:1.36**	S:0.19** SE:0.12** SxSE:0.27**	S:5.68** SE:3.44** SxSE:7.70**

[1]: RL:Root length; SL:Shoot length; RFW:Root fresh weight;SFW:Shoot fresh weight; RDW:Root dry weight;SDW:Shoot dry weight; RWC: Relative water content; SE: seaweed extract; S: Salinity. Data represent means of four replications ± standard errors; mean values in the same column followed by the different letters indicate a significant difference by least significant difference test (*: significant at p<0.05, **: significant at p<0.01).

Additionally, It was found that foliar application of seaweed extract significantly increased root and shoot lengths and fresh weight parameters in tomato plants grown under different irrigation conditions and salinity stress (Hernández-Herrera et al., 2022).

In another study conducted under laboratory and greenhouse conditions, different types of seaweeds were reported to improve root length, shoot length, fresh weight and dry weight parameters of tomato plants. It was also reported that seaweed applications positively affected the root system of the plants and thus promoted germination and growth of the plant, as the roots sufficiently utilized nutrients from deeper soil layers (Hernández-Herrera et al., 2014). The results of foliar application of seaweed on shoot lengths and fresh weights in wheat grown under saline conditions indicate that seaweed extract alleviates the negative effects of salinity (Latique, 2021). Studies on seaweed extracts have shown that seaweeds increase lateral root development, root extension, plant growth, shoot lengths, biomass (Finnie and Van Staden, 1985; Crouch and Van Staden, 1991;1993; Bulgari et al., 2019; Ribeiro, 2022). The results of this study and the findings of the researchers on root length, shoot length, root dry and fresh weights, shoot dry and fresh weights are supportive of each other.

The effect of salinity on relative water content values was negative. While the value was 83.12 % in the control group, the values decreased gradually as the salt doses increased (51.04 % '100 mM', 49.68 % '150 mM', 47.42 % '200 mM'). Seaweed treatments also had no positive effect on relative water content values. When the values in the interactions were analyzed, the control group gave the highest value (109.51 %), while the lowest value was recorded in the 200 mMx4 g L^{-1} treatment (34.30 %) (Table 1; Figure 1). The highest relative water content value in peppermint was found in the group without salinity stress and the positive effects of salinity and foliar seaweed applications were not found. With increasing salinity, water absorption in peppermint decreases due to the reduction in water potential, resulting in the plant's inability to retain water in its leaves, which leads to wilting (Hakimzadeh and Esfandiari, 2022). In this study, the reason for the decrease in RWC values under salinity stress is due to high salt concentrations in the external environment, leading to osmatic potential and dehydration at the cellular level (Shahverdi et al., 2017).

Figure 1. Effects of NaCl and Seaweed Extract Concentrations on Growth Characteristics of Safflower

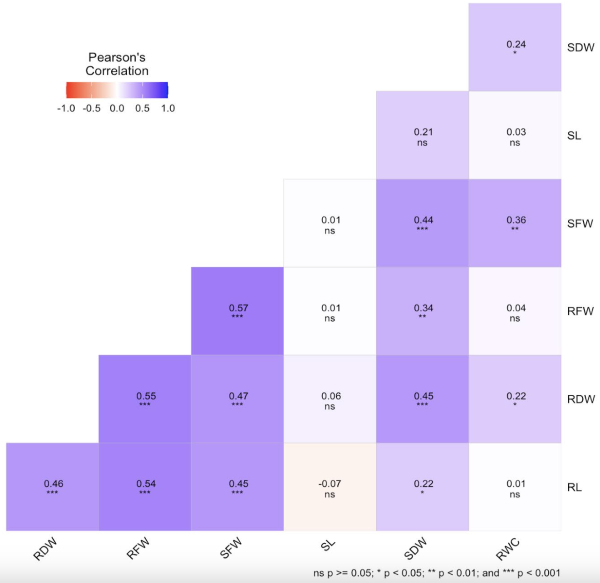

Figure 2. Correlation coefficient between 7 morphological parameters affected by different levels of salinity and seaweed treatments

The findings that salinity stress reduces the relative water content in leaves and that foliar application of seaweed alleviates this reduction have been reported by many researchers (Shahi et al., 2015; Chanthini et al., 2022). The data on relative water content in this study were found to be in parallel with the findings of the researchers partly.

Correlation analysis Growth Parameters of Safflower Plants

The effects of different doses of salt and seaweed (SE) applications on growth parameters of safflower were examined and correlation analysis (Pearson correlation) was performed to determine the relationships between these parameters. A positive correlation was observed between all traits except root and shoot length. Root length x root fresh weight (RL x RFW), root dry weight x root fresh weight (RDW x RFW), root and shoot fresh weight (RFW x SFW), root length x root dry weight (RL x RDW), root length x shoot fresh weight (RL x SFW), A moderate positive correlation (r=0. 40-0.60***) was found between root dry weight x shoot dry weight (RDW x SDW), root dry weight x shoot fresh weight (RDW x SFW) and shoot fresh weight x shoot dry weight (SFW x SDW) (Figure 2. 40-0.60***) was found (Figure 2).

Effect of the SE and Salinity Treatments on Elemental Composition of Plant Nutrients in Shoot and Root of Safflower

As shown in Table 2, salinity, seaweed and saltxseaweed interactions were statistically significant at 1% significance level for B, Fe, K and Mg microelements in safflower shoots. On the other hand, in terms of Ca and Cu elements, the difference between the numbers in seaweed treatments was not significant, while the difference between the numbers in terms of salinity and saltxseaweed interactions was significant at 1% significance level. In terms of microelements in the root, Cu, Fe, K, Mg concentrations were statistically significant at 1% significance level in all parameters, while there was no statistical difference between the doses in seaweed treatments for B and Ca microelements, the differences between the figures in other parameters were statistically significant at 1% significance level (Table 3).

While the B contents in the shoot were in the same group (a) in the control and 50 mM dose under salt stress (34.60 mg kg^{-1}, 33.13 mg kg^{-1}, respectively), the values decreased as the salt stress increased and the lowest value was found in group (c) at 200 mM dose (21.28 mg kg^{-1}). In seaweed treatments, the highest value was obtained from 2 g L^{-1} dose (32.21 mg kg^{-1}), while the lowest value was found in the control group (24.27 mg kg^{-1}). In the saltxseaweed interaction, controlx2 g L^{-1} application (40.20 mg kg^{-1}) represented group (a) and 200x6 g L^{-1} application (18.68 mg kg^{-1}) was in group (j). Seaweed treatments generally alleviated the negative effects of salinity. The difference between seaweed treatments in Ca and Cu contents in the shoot was insignificant. The highest (20721.25 mg kg^{-1}) and the lowest (16008.65 mg kg^{-1}) Ca values were recorded at 100 mM salt doses in the control group. As saltxseaweed interaction, the highest value (25689.25 mg kg^{-1}) was found in 100 mMxcontrol treatment and the lowest value (14019.92 mg kg^{-1}) was found in controlx2 g L^{-1} treatment. For Cu values, the highest value was found in 100 mM (3.75 mg kg^{-1}) and 150 mM (3.50 mg kg^{-1}) salt doses, while the other doses were classified in the same group. In saltxseaweed interaction, 100 mMxcontrol treatment represented group (a) with 4.77 mg kg^{-1}, while controlxcontrol treatment was in group (g) with 1.78 mg kg^{-1} (Table 2). The highest B content in the root was found at 50 mM salt dose (20.24 mg kg^{-1}), while the other doses were in the same group (b). There was no statistical difference between the doses in seaweed treatments. In terms of interactions, the highest value was obtained from 2 and 4 g L^{-1} (25.15, 23.88 mg kg^{-1}) at 100 mM salt dose, while the lowest value was determined from 50 Mmx2 g L^{-1} (7.25 mg kg^{-1}). According to the Cu concentrations in the root, it can be said that the values increased as the salt and seaweed doses increased. When the figures were evaluated according to their interactions, it was recorded that the values increased gradually as the seaweed increased in salt doses (Table 3).

Table 2. Effects of NaCl and Seaweed Extract Concentrations on Plant Nutrient Elements of Safflower Shoots-1

Applications		Parameters					
NaCl (mM)	SE (g L^{-1})	B (mg kg^{-1})	Ca (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})
Control (S0)	0	28.66ef[1] ef[1]	14889.49 fg	1.78 g	35.10 h	46258.46 b-h	2646.41 d-f
	2	40.20 a	14019.92 g	3.71 bc	68.29 e	48512.23 ab	3676.35 a
	4	36.13 bc	17400.79 d-g	3.27 c-f	45.30 g	43728.50 f-j	3593.16 a
	6	33.38 cd	17724.39 d-g	4.16 ab	37.25 h	46941.24 a-f	3651.71 a
S0 average		34.60 a	16008.65 c	3.23 b	46.48 e	46360.11 a	3391.91 a
50 (S1)	0	27.51 e-g	15990.59 e-g	2.61 f	53.54 f	42341.75 ı-k	2612.60 d-f
	2	38.82 ab	23059.58 ab	3.25 c-f	53.93 f	42947.34 h-k	3447.29 ab
	4	31.10 de	19640.42 b-e	2.83 ef	46.70 g	43241.72 g-k	2387.99 f
	6	35.09 b-d	18765.3 de	2.80 ef	46.13 g	42834.77 ı-k	3484.65 a
S1 average		33.13 a	19363.97 ab	2.87 b	50.08 d	42841.39 b	2983.13 b
100 (S2)	0	24.06 g-ı	25689.25 a	4.77 a	46.71 g	48296.97 a-d	3608.27 a
	2	29.10 ef	18904.43 c-e	2.92 d-f	74.88 d	44805.91 e-ı	2694.90 d-f
	4	24.44 g-ı	18414.66 d-f	3.64 b-d	75.37 d	46585.44 a-g	2757.15 d-f
	6	25.89 f-h	19876.68 b-d	3.68 bc	93.54 b	44912.99 d-ı	2548.54 ef
S2 average		25.87 b	20721.25 a	3.75 a	72.62 c	46150.33 a	2902.21 bc
150 (S3)	0	23.21 hı	22555.65 a-c	3.68 bc	112.26 a	48370.23 a-c	2960.85 c-e
	2	25.36 f-h	20070.87 b-d	3.85 bc	83.65c b-d	44788.80 e-ı	3023.69 b-d
	4	25.48 f-h	19145.99 c-e	3.64 b-d	74.89 d	44967.85 c-ı	3306.44 a-c
	6	25.09 f-h	18848.09 c-e	3.64 b-d	77.54 d	49885.94 a	2908.61 c-e
S3 average		24.78 b	20155.15 ab	3.70 a	87.08 a	47003.20 a	3049.90 b
200 (S4)	0	17.89 ı	18005.50 d-f	3.80 bc	74.70 d	40107.46 k	2344.66 f
	2	27.60 e-g	18779.13 de	3.50 b-e	86.33 c	40548.89 jk	2721.30 d-f
	4	20.96 ıj	20779.35 b-d	2.58 f	72.75 de	47229.50 a-e	2928.10 c-e
	6	18.68 j	18023.97 d-f	2.62 f	67.14 e	47926.61 a-e	2657.14 d-f
S4 average		21.28 c	18896.99 b	3.13 b	75.23 b	43953.11 b	2662.80 c
SE average	0	24.27 c	19426.10	3.33	64.46 b	45074.97 ab	2834.56 b
	2	32.21 a	18966.78	3.45	73.42a	44320.63 b	3112.70 a
	4	27.62 b	19076.24	3.19	63.00b	45150.60 ab	2994.57 ab
	6	27.63 b	18647.69	3.38	64.32b	46500.31 a	3050.13 a
LSD (%)		S:3.18** SE:1.80** SxSE:4.02**	S:1807** SE:ns SxSE:3772**	S:0.43** SE:ns SxSE:0.74**	S:2.44** SE:2.55** SxSE:5.70**	S:1754** SE:1529** SxSE:3418**	S:2960** SE:205.9** SxSE:460.3**

[1]Means shown with the same letters in the same group and column are not significantly different, *: significant at p<0.05 level, **: significant at p<0.01 level, S: salinity, SE: seaweed extract, ns: not significant.

Boron is a factor in the structural and functional integrity of cell walls and membranes, cell division and elongation, nitrogen, carbohydrate, sugar, protein, enzyme and nucleic acid metabolism in plants (Zaib, 2024). It has been reported that the oxidative damage caused by salinity stress is alleviated by the level of B in the soil (Kohli et al., 2023), and in the study in which *Ascophyllum nodosum* extract was applied in maize, the values of Ca, Mg, S, Fe, Cu, Mn, Mo, Zn contents including B content in leaf analyses increased compared to the control (Ertani et al., 2018). In a study conducted by Mutlu Durak et al. (2023), salt application increased P and Mg concentrations in the shoot of maize plant, while Ca and S concentrations in the shoot decreased. In different biostimulant applications, P concentration in the shoot decreased at high doses and had no effect on Mg content. Biostimulants decreased Ca content and increased S content in the shoot of maize at high doses of salt applications. Biostimulant had no effect on Fe, Zn, Mn, Cu, Mo contents in the shoot in salt applications in the control group. As the salt doses increased, Fe, Zn and Mn contents in the shoot increased and Mo content decreased by 80%. *Ascophyllum nodosum* extract applications reduced the effects of salinity stress in avocado and increased K and Ca contents in leaves (Bonomelli et al., 2018). In pumpkin plants grown under salinity stress, Ca content increased and Mg content decreased as the salt dose increased. P, K, Ca concentrations in roots and leaves of *Zuccini squash* were adversely affected by salt applications and biostimulant applications alleviated the decrease in K content (Rouphael et al., 2017). The responses of the microelements mentioned in the literature to salinity and seaweed extract were similar.

Fe values in the shoot increased up to 150 mM salt dose and decreased slightly at 200 mM. While the highest Fe value was determined at 2 g L^{-1} in seaweed treatments, Fe amounts varied inversely with increasing doses. According to the interactions, Fe amounts showed significant variability and 100 mMxcontrol seaweed was classified in group (a), while the lowest value was recorded at 0 and 6 g L^{-1} in the control salt treatment and constituted group (h). Fe values in the root varied according to the salt doses. At 100 mM, 509.60 mg kg^{-1} was classified in group (a), while the lowest values were recorded at the control (107.61 mg kg^{-1}) and 50 mM (48.87 mg kg^{-1}) doses and were in group (d).

Table 3. Effects of NaCl and Seaweed Extract Concentrations on Plant Nutrient Elements of Safflower Roots-1.

Applications		Parameters					
NaCl (mM)	SE ($g L^{-1}$)	B ($mg kg^{-1}$)	Ca ($mg kg^{-1}$)	Cu ($mg kg^{-1}$)	Fe ($mg kg^{-1}$)	K ($mg kg^{-1}$)	Mg ($mg kg^{-1}$)
Control (S0)	0	11.70 c-g[1]	22131.30 a-c	6.32 d-f	98.35 hı	24554.21 b	1657.65 f-ı
	2	10.49 d-g	10249.73 ef	4.51 e-h	115.65 g-ı	26219.95 b	1610.58 f-ı
	4	12.33 b-e	15103.52 b-e	5.47 e-g	151.97 f-ı	22930.88 bc	2094.26 c-f
	6	10.66 c-g	17601.05 b-e	2.47 gh	64.47 ı	21820.94 b-d	1841.05 d-h
S0 average		11.30 b	16271.40 b	4.69c	107.61d	23881.50a	1800.88c
50 (S1)	0	14.01 b-d	10477.83 ef	3.83 f-h	54.37 ı	26707.64 b	1740.74 e-ı
	2	7.25 g	2608.38 f	1.97 h	32.93 ı	26530.84 b	2729.80 bc
	4	8.29 e-g	16667.98 b-e	2.53 gh	57.21 ı	27224.87 b	2440.10 b-d
	6	13.96 b-d	13163.74 de	4.06 f-h	50.97 ı	18750.18 b-d	3581.89 a
S1 average		20.24 a	10729.48 c	3.09 c	48.87 d	24803.38 a	2623.13 a
100 (S2)	0	16.61 b	14351.87 c-e	3.68 a-d	56.94 ı	12703.44 b-e	1910.31 d-g
	2	25.15 a	16509.12 b-e	7.70 de	473.25 bc	48438.45 a	2404.52 b-e
	4	23.88 a	26978.81 a	11.94 bc	908.56 a	13163.19 b-e	2915.68 ab
	6	15.33 bc	19907.38 a-d	9.41 cd	599.66 b	14670.59 b-e	1756.41 d-ı
S2 average		10.88 b	19436.79 a	8.18 b	509.60 a	22243.92 a	2246.73 b
150 (S3)	0	10.40 d-g	16484.43 b-e	6.48 d-f	469.71 bc	15960.54 b-e	1135.74 ıj
	2	9.87 d-g	13245.52 de	11.52 bc	346.74 cd	17213.78 b-e	1484.04 f-j
	4	8.44 e-g	13408.59 de	11.93 bc	313.19 de	15331.82 b-e	1359.23 g-j
	6	9.71 d-g	13803.31 de	12.34 bc	283.84 d-f	7437.50 c-e	1263.03 g-j
S3 average		9.60 b	14235.46 b	10.57 b	353.37 b	13985.91 b	1310.51 d
200 (S4)	0	10.40 d-g	22380.07 ab	13.51 ab	200.40 e-h	18119.34 b-d	1194.77 h-j
	2	9.95 d-g	13515.93 de	16.16 a	242.06 d-g	8342.46 c-e	1406.32 f-j
	4	7.40 fg	10867.63 e	13.83 ab	301.05 de	2474.52 e	915.48 j
	6	12.04 b-f	14526.75 b-e	15.64 a	203.60 e-h	6643.82 de	1391.14 g-j
S4 average		9.95 b	15322.59 b	14.79 a	236.78 c	8895.04 b	1226.93 d
SE average	0	12.62	17165.10 a	6.76 b	175.95 c	19609.03 ab	1527.84 b
	2	12.54	11225.73 b	8.37 a	242.13 b	25349.10 a	1927.05 a
	4	12.07	16605.31 a	9.14 a	346.40 a	16225.06 b	1944.95 a
	6	12.34	15800.45 a	8.78 a	240.51 b	13864.61 b	1966.71 a
LSD (%)		S:1.91** SE: ns SxSE:4.73**	S:3081** SE: 3585** SxSE:8017**	S:2.44** SE:1.53** SxSE:3.41**	S:65.42** SE:60.23** SxSE:134.7**	S:6593** SE:6941** SxSE:15520**	S:341.4** SE:308.6** SxSE:690.1**

[1]Means shown with the same letters in the same group and column are not significantly different, *: significant at p<0.05 level, **: significant at p<0.01 level, S: salinity, SE: seaweed extract, ns: not significant.

Fe values increased as the seaweed doses increased, but the highest value was observed at 4 $g L^{-1}$ (346.40 $mg kg^{-1}$), while a slight decrease was observed at 6 $g L^{-1}$ (240.51 $mg kg^{-1}$). Significant differences were observed in Fe content according to the interactions. While the highest value was recorded from 4 $g L^{-1}$ seaweed applied at 100 mM salt dose, the lowest value was obtained from the control seaweed application of the same salt dose, and all seaweed amounts applied at 50 mM salt dose and controlx6 $g L^{-1}$ were in the same group (Table 2 and 3). In a study with the same results with these data, Mg, Mn, Ca concentrations in barley decreased with increasing salt levels (Cramer et al., 1991).

K concentrations in the shoot had the highest values at control, 100 mM, 150 mM salt doses, while the lowest values were measured at 50 mM and 200 mM doses. Among the seaweed doses, K level at 6 $g L^{-1}$ (46500.31 $mg kg^{-1}$) was in group (a), while at 2 $g L^{-1}$ (44320.63 $mg kg^{-1}$) was in group (b) and the lowest value was recorded. When the figures for the interactions were evaluated, different results were obtained and the highest K concentration was determined at 150 mMx6 $g L^{-1}$ (49885.94 $mg kg^{-1}$). The lowest value was read at 200 mMx0 $g L^{-1}$ (40107.46 $mg kg^{-1}$). The K amounts in the root were in the same group in control (23881.50 $mg kg^{-1}$), 50 mM (24803.38 $mg kg^{-1}$), 100 mM (22243.92 $mg kg^{-1}$) salt doses (a), and when evaluated numerically, K amounts decreased as the salt doses increased. The highest K amount (25349.10 $mg kg^{-1}$) was determined at 4 $g L^{-1}$ in seaweed treatments and it can be said that K amounts decreased as the doses increased. For K values in terms of the interactions, the lowest value was measured at 200 mMx 4 $g L^{-1}$ (2474.52 $mg kg^{-1}$) and the highest value was measured at 100 mMx 2 $g L^{-1}$ (48438.45 $mg kg^{-1}$).

According to Mg concentrations, the values increased with increasing salt doses in shoot analyses, while the values were higher in root analyses except for the control group. In seaweed treatments, the highest Mg concentrations were recorded at 2 and 6 $g L^{-1}$ in the shoot and 2,4,6 $g L^{-1}$ in the root and represented group (a). When the values in the interactions were compared, Mg concentrations in the shoot were in group (a) except for the control seaweed at the control salt dose. The highest value was determined in 50 mMx6 $g L^{-1}$ and 100 mMxcontrol interactions in the same group. The lowest value was determined in 200 mMxcontrol (2344.66 $mg kg^{-1}$) interaction (Table 2 and 3).

Table 4. Effects of NaCl and Seaweed Extract Concentrations on Elemental Composition of Plant Nutrients of Safflower Shoots-2.

Applications		Parameters				
NaCl (mM)	SE (g L^{-1})	Mn (mg kg^{-1})	Na (mg kg^{-1})	P (mg kg^{-1})	S (mg kg^{-1})	Zn (mg kg^{-1})
Control (S0)	0	28.09 h[1]	457.02 j	5581.97 e	1551.27 c	40.90 c-e
	2	67.64 a	554.15 j	9620.45 a	2915.34 c	44.99 bc
	4	47.12 e	626.67 j	7536.41 e	2366.64 c	34.53 fg
	6	39.70 g	729.34 j	7454.58 e	2474.04 c	41.05 c-e
S0 average		45.64 d	591.79 e	7548.35 b	2326.82 d	40.36 bc
50 (S1)	0	39.10 g	2034.90 h	8566.32 b	1498.36 c	46.62 b
	2	56.09 cd	1363.33 ı	8269.27 b	2208.08 c	43.88 b-d
	4	45.27 ef	2572.28 ef	7462.17 c	2248.64 c	38.07 ef
	6	52.39 d	2193.39 f-h	7374.34 c	2443.97 c	43.35 b-d
S1 average		48.21 c	2040.97 d	7918.02 a	2099.76 d	42.98 ab
100 (S2)	0	46.09 ef	2448.18 e-g	8459.95 b	2168.71 c	57.28 a
	2	61.70 b	2068.84 gh	7503.60 c	1796.27 c	37.15 ef
	4	46.15 ef	2675.82 e	6574.00 d	125370.78 a	36.94 ef
	6	55.93 cd	3496.20 d	6400.07 d	123049.15 a	36.12 e-g
S2 average		52.47 b	2672.26 c	7234.41 c	63096.23 c	41.87 bc
150 (S3)	0	68.22 a	4411.89 c	7618.96 c	128390.20 a	44.75 bc
	2	57.94 bc	4447.47 c	7391.47 c	128918.38 a	54.30 a
	4	55.06 cd	3808.15 d	8401.55 b	129744.27 a	44.42 b-d
	6	54.02 cd	3702.39 d	6577.82 d	125755.62 a	39.30 d-f
S3 average		58.81 a	4092.47 b	7497.45 bc	128202.12 a	45.69 a
200 (S4)	0	47.19 e	5351.48 b	6410.18 d	132150.79 a	31.28 g
	2	55.10 cd	4669.10 c	6208.45 d	126717.24 a	45.31 bc
	4	56.05 cd	5878.95 a	5569.44 e	129145.20 a	45.36 b
	6	41.10 fg	5482.32 ab	5659.64 e	83659.22 b	37.81 ef
S4 average		49.86 c	5345.46 a	5961.93 d	117918.11 b	39.94 c
SE average	0	45.74 c	2940.69 b	7327.48 b	53151.87 c	44.16 a
	2	59.69 a	2620.58 c	7798.65 a	52511.06 c	45.12 a
	4	49.93 b	3112.37 ab	7108.71 b	77775.11 a	39.86 b
	6	48.63 b	3120.73 a	6693.29 c	67476.40 b	39.53 b
LSD (%)		S:2.47**	S:279.4**	S:518.6**	S:14590**	S:5.15**
		SE:7.12**	SE:177.9**	SE:231.9**	SE:6524**	SE:2.30**
		SxSE:5.07**	SxSE:397.8**	SxSE:308.1**	SxSE:9546**	SxSE:2.81**

[1]Means shown with the same letters in the same group and column are not significantly different, *: significant at $p<0.05$ level, **: significant at $p<0.01$ level, S: salinity, SE: seaweed extract, ns: not significant.

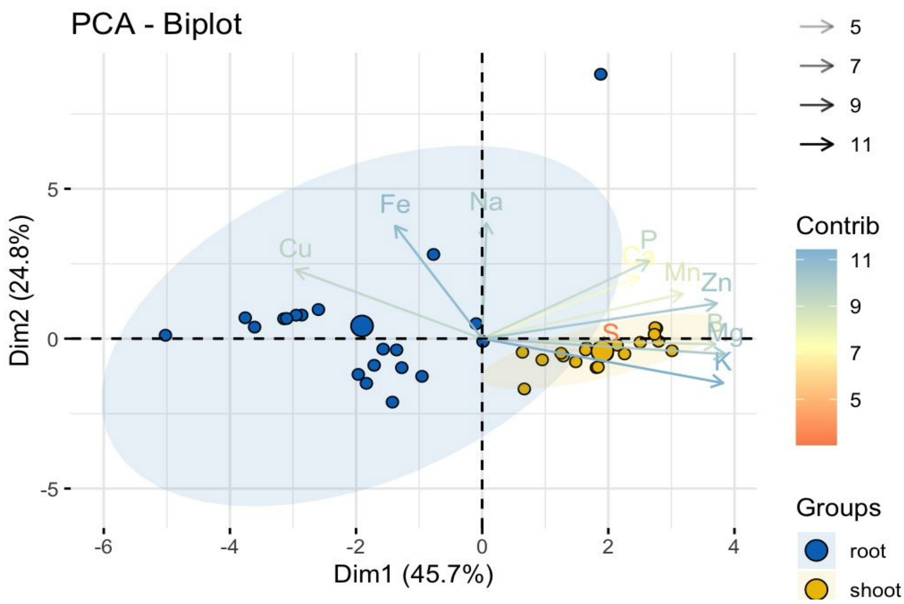

Figure 3. PCA biplot (Principal component-1 PC1 vs. Principal component-2 PC2) visualizing correlations between elemental contents in shoot and root affected by different levels of salinity and seaweed treatments

Table 5. Effects of NaCl and Seaweed Extract Concentrations on Elemental Composition of Plant Nutrients of Safflower Roots-2.

Applications		Parameters				
NaCl (mM)	SE (g L^{-1})	Mn (mg kg^{-1})	Na (mg kg^{-1})	P (mg kg^{-1})	S (mg kg^{-1})	Zn (mg kg^{-1})
Control (S0)	0	34.33 de	841.32 ef	5475.69 c	18453.93 a	26.98 c-f
	2	32.69 de	669.77 f	6316.33 c	16209.61 b	25.50 d-f
	4	32.25 de	513.50 f	5331.87 cd	18141.56 a	24.22 ef
	6	23.24 e	679.12 f	3729.60 c-e	17561.27 ab	25.53 d-f
S0 average		30.63 b	675.93 c	5213.37b	17591.59 a	25.56b
50 (S1)	0	46.45 cd	2718.33 c-f	6515.17 c	17216.45 ab	25.52 d-f
	2	55.39 bc	1978.66 d-f	3226.25 c-e	16618.96 ab	27.16 c-f
	4	67.54 ab	4115.60 b-e	6647.57 c	2873.13 cd	31.90 b-e
	6	37.89 de	5120.97 b-d	1528.60 e	2469.13 c-e	32.30 b-e
S1 average		51.82 a	3483.39 b	4479.40 b	9794.42 b	29.22 b
100 (S2)	0	33.29 de	6292.51 b	6279.06 c	2294.60 c-e	26.73 c-f
	2	56.94 bc	4937.98 b-d	1783.82 e	2701.49 cd	35.98 b-d
	4	76.78 a	31620.94 a	16489.02 a	3209.75 cd	54.39 a
	6	55.95 bc	3097.86 b-f	10968.56 b	2734.66 cd	36.53 bc
S2 average		55.74 a	11487.32 a	8880.11 a	2735.13 c	38.41 a
150 (S3)	0	34.77 de	4207.45 b-e	5350.72 c	2025.41 c-e	19.60 fg
	2	28.38 e	6324.34 b	4596.56 c-e	1745.81 c-e	30.51 b-e
	4	34.52 de	5417.93 bc	4372.50 c-e	1763.87 c-e	26.46 c-f
	6	30.44 e	4146.11 b-e	3480.45 c-e	1417.44d e	24.25 ef
S3 average		32.03 b	5023.96 b	4450.06 b	1738.13 d	25.20 b
200 (S4)	0	30.95 e	5565.06 bc	4080.78 c-e	3623.33 c	29.10 b-f
	2	27.41 e	4948.71 b-d	4563.48 c-e	1752.11 c-e	23.52 ef
	4	27.74 e	5171.02 b-d	1923.43 de	652.89 e	11.16 g
	6	29.04 e	4190.36 b-e	3550.84 c-e	1755.42 c-e	38.21 b
S4 average		28.78 b	4968.79 b	3529.63 b	1945.94 cd	25.50 b
SE average	0	35.96 b	3924.93 b	5540.28 ab	8722.74 a	25.58 b
	2	40.16 b	3771.89 b	4097.29 b	7805.59 b	28.54 ab
	4	47.77 a	9367.80 a	6952.88 a	5328.24 c	29.62 a
	6	35.31 b	3446.88 b	4651.61 b	5187.59 c	31.36 a
LSD (%)		S:5.56** SE:6.62** SxSE:14.81**	S:1828** SE:1534** SxSE:3429**	S:1760** SE:3423** SxSE:1531**	S:826** SE:858** SxSE:1920**	S:7.47** SE:3.65* SxSE:10.90**

[1]Means shown with the same letters in the same group and column are not significantly different, *: significant at p<0.05 level, **: significant at p<0.01 level, S: salinity, SE: seaweed extract, ns: not significant.

The highest value of Mg content in the root was determined at 50 mM salt dose, while the lowest value was determined at 150 mM and 200 mM doses in the same group. In terms of seaweed doses, except for the control group, the others were classified in group (a). According to the interactions, the highest Mg content was recorded at 50 mMx6 g L^{-1}, while the lowest concentration was recorded at 200 mMx4 g L^{-1} (Table 2 and 3).

As shown in Table 4, the effects of salinity, seaweed, and saltxseaweed interactions on the concentrations of Mn, Na, P, S, and Zn microelements in safflower shoots were statistically significant at the 1% significance level. For root concentrations of Mn, Na, P, and S, all parameters were found to be statistically significant at the 1% level. However, for Zn microelements in seaweed treatments, the differences between doses were statistically significant at the 5% level, while differences in the other parameters were significant at the 1% level, as detailed in Table 5When the data of Mn contents were analysed, Mn concentrations increased with increasing salt concentrations in the shoot and decreased slightly at 200 mM salt dose. In seaweed applications, while it was the lowest value in control, it was the highest value at 2 and 4 g L^{-1}, while there was no statistical difference between the figures in other increasing seaweed doses. Mn contents showed variability in terms of interactions and seaweed had no effect on increasing salt doses. While 50 mM and 100 mM salt doses were in group (a) for Mn contents in the root, the other doses were in the same group (b) including the control. Mn concentrations in the root increased as the seaweed treatments increased, and a slight decrease was recorded at the highest dose. In the interactions, different results were obtained in each treatment and the highest value was obtained in the 100 mM x 4 g L^{-1} interaction, and seaweed had little effect on Mn contents caused by salt stress (Tables 4 and 5).

The values obtained for Na content in the shoot increased with increasing salt content. In seaweed application, Na results increased as the doses increased except for 2 g L^{-1} application. While the lowest Na contents were found in all seaweed doses in the control salt dose, the highest Na value (5878.95 mg kg^{-1}) was read in the 200 mMx 4 g L^{-1} interaction. While Na contents in the root were the lowest in the control salt dose, Na values increased as the doses increased, but the highest value was found in the 100 mM dose (11487.32 mg kg^{-1}). According to the seaweed doses, the highest Na value was determined at 4 g L-1 (9367.80 mg kg^{-1}), while there was no statistical difference in other doses (Tables 4 and 5).

In a study conducted by Hatami et al. (2023), seaweed applications (0.25, 0.5 g L^{-1}) on palm trees resulted in higher values of P, K, Ca, Mg, and Mn at the 0.5 g L^{-1} dose, but there was no difference in Zn content between the seaweed doses applied. Particularly, the contents of P and K were positively directly affected by seaweed applications. In a study on strawberries, different seaweed doses (0 mL L^{-1}, 3 mL L^{-1}) yielded higher results in N, P, K, and Mg contents with the 3 mL L^{-1} application (Consentino et al., 2023). In a study conducted on bell peppers, it was found that Na concentrations in the leaves increased as the salt content increased, but seaweed doses reduced the salt-induced Na concentration to a certain level. The amounts of K and P in the leaves decreased gradually as the salt levels increased, and the effect of seaweed increased proportionally to the amounts of K and P. On the other hand, it was reported that the content of plant nutrients, especially K and P nutrients, decreased at high Na concentrations (Pal et al., 2024). In their study on salinity and seaweed in eggplants, Hegazi et al. (2015) found that salinity stress increased Na content and decreased K content in eggplants and their fruits. Additionally, seaweed applications were effective in increasing K content. There are some relationships between plant nutrients in plants. High Na content prevents K uptake. Excessive Na content in the soil produces negative results in plants. Moreover, Na uptake negatively affects the Ca and Mg uptake of plants (Kopittke, 2012; Ketehouli et al., 2019). The data in this study are in agreement with the responses of microelements reported in the literature.

Principal Component Analysis (PCA) For Elemental Composition of Plant Nutrients in Shoot and Root of Safflower

Principal component analysis (PCA) was used to show the relationship between salinity and seaweed treatments and elemental contents in shoots and roots (Figure 3). In PCA analysis, the first and second principal components represented 70.5% of the total variation (PC1 45.7%, PC2 24.8%), indicating that the analysis represents the total variation at an acceptable level. The close proximity of the objects on the PCA Biplot graph means that there is a positive relationship between them, while the length of the vectors representing the traits means that the contribution of these traits to the total variation is high (Torres-Salinas et al., 2013). The distance between the points in the PCA Biplot graph represents the relationship between the elemental contents of the root and shoot. The elemental contents of the shoots obtained at the end of the treatments are shown in the right part of the biplot and have higher elemental contents than the roots. When the elements were analyzed individually, only Fe, Cu and Na were higher in roots, while the other elements (B, Ca, P, Zn, Zn, Mg, K, S, Mg) were higher in shoots. In particular, most of the treated samples appear in the right part of the biplot, and their position relative to the loads indicates that they have higher elemental contents than the controls. Similarly, the contents found in roots generally appear to be higher than those found in leaves, since root samples generally appear in the right part of the biplot.

Conclusion

In this study conducted under climate chamber conditions, seaweed applications minimized the negative results caused by salt doses applied to Dinçer safflower variety. Positive results were obtained from seaweed applications in root and shoot plant nutrient contents of safflower plant. The use of seaweed, which is one of the innovative biostimulants in agriculture, especially in soil conditions with high salinity, which is one of the abiotic stress conditions, was supported by this study. In terms of practical application, it is absolutely necessary to carry out seaweed studies in saline soils at different doses and application times in field studies for clearer results. In this study, it was clear that seaweed had significant effects on plant nutrient contents and morphological characteristics of the plant in different amounts of salt and seaweed applied to pots. When the data obtained from this study were examined, the most appropriate seaweed applications could be recommended at doses of 4 g L^{-1} for plant nutrient contents and 6 g L^{-1} for morphological characters. However, it is important for future studies to evaluate the economic aspects and to determine the appropriate dose in field studies.

Declarations

Author Contribution Statement

NÇK: Data collection, investigation, formal analysis, and writing the original draft

MTE: Project administration, supervision, methodology, review and editing

Conflict of Interest

The authors declare no conflict of interest.

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