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Research Article

Effects of salinity stress and foliar application of mineral elements and methanol on growth and some physiological traits of *Coriandrum sativum* L.

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Abstract

The idea was to assay the salinity (0, 50 and 100 mM) impacts on *Coriandrum sativum* by the foliar application of nano-Zn, $FeSO_4$, $MgSO_4$ and methanol in possibly the salinity stress side-effects. A factorial experiment was arranged based on a completely randomized design with three replications in pot at Azarbaijan Shahid Madani University. The results revealed that salinity × foliar treatment significantly affected plant dry weight, relative water content, catalase activity, and elemental content of plants. The top recorded data (P≤5%) for, plant dry weight and chlorophyll b content was with non-salinity × all foliar treatment. No-salinity and $NaCl_{50mM}$ × methanol foliar application increased K content in plant. 50 mM NaCl × $FeSO_4$ and nano-Zn spray increased catalase activity. Foliar spray with methanol, $FeSO_4$ and nano-Zn × no salinity increased N content. The highest relative water content belonged to no salinity × $FeSO_4$ and nano-Zn and $NaCl_{50\ mM}$ × $FeSO_4$ treatment. The top content of Fe, P, Ca and K/Na were recorded at non-saline conditions. 50 mM NaCl increased the essential oil content of the plant. 100 mM salinity treatment increased malondialdehyde, H_2O_2, Na and proline contents. Foliar treatment with $FeSO_4$ and $MgSO_4$ increased the essential oil content of the plant. As well *Coriandrum sativum* was sensitive plants to salinity, and foliar treatments especially $FeSO_4$ and nano-zinc ameliorated the adverse side-effects of salinity in plants.

Keywords: *Coriandrum sativum,* Catalase activity, Malondialdehyde, Nutrient content

Introduction

Coriandrum sativum is an annual, aromatic, and medicinal herb from the Apiaceae family (Mandal and Mandal, 2012). Owing to their aromatic constituents, coriander fruits are commonly used as spice and food ingredients. In folk medicine, coriander's essential oil is a stimulant of gastric secretion, benefits as a carminative, estrogen, spasmolytic, antibacterial, antifungal effects and reduces blood pressure (Mandal and Mandal, 2012). Coriander has extensive adaptation and grows well in most soil and climate conditions, but the growing environment influence secondary metabolic profile in plants (Vojodi Mehrabani *et al.,* 2018a; Rabiei *et al*., 2020).

Salinity is one of the serious environmental problem encountered in agricultural systems in arid and semi-arid regions. Salinity directly impacts plant growth and productivity (Rodrigues *et al*., 2020). Under salinity stress, excess Na^+ and Cl^- accumulate in the rhizosphere and reduce osmotic pressure, and interferes with ionic homeostasis. Moreover, salinity stress cause oxidative damage by producing activated oxygen species (superoxide, hydrogen peroxide, hydroxyl radicals) damage to the cell membrane, DNA, RNA, proteins, and photosynthetic apparatus of plants (Tsamaidi *et al*., 2017; Cai and Gao, 2020), these disturbances by affecting physiological mechanisms, lead to the reduced plant growth and productivity. Under salinity stress, plants use enzymatic (superoxide dismutase, ascorbate peroxidase, catalase and glutathione peroxidase) and non-enzymatic mechanisms (proline, ascorbate and glutathione) in a face to stress (Munns and Tester, 2008). Understanding the mechanisms of plant tolerance to salinity can help improve growth and plant productivity. Using some chemical compounds (natural or synthetic) as a foliar spray is an emerging way to reduce the negative effects of salinity stress in the plant (Vojodi Mehrabani *et al*., 2018b).

Methanol foliar application is one of the strategies for increasing intracellular CO_2 concentration in plants. Methanol is a simple compound for plants metabolism. During leaf growth, methanol is made by demethylation of pectin in the cell walls (Ehyaei *et al*., 2010; Gout *et al.,* 2000). Methanol is used as a hydrocarbonic compound in plants, activates several enzymes, enhances photosynthesis and also by the combination with ribulose-1-5-biphosphate (a regulatory key enzyme in carbon metabolism) enhances plant growth (Gout *et*

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al., 2000). Foliar spraying with methanol under salinity stress in *Pelargonium graveolens* enhanced IC_{50}, root dry weight, Fe, K and essential oil content of plants (Vojodi Mehrabani, 2019). Under salinity stress, nutrient treatments had a positive role in plant growth and yield. Magnesium (Mg) is one of the important macronutrients in plants. Mg has different physiological functions: For example, magnesium is the central atom of chlorophyll, activates enzymatic processes and influences plant assimilation. Magnesium deficiency reduces chlorophyll content, causes leaf chlorosis and reduces yield (Marschner, 2012). In *Vitis vinifera*, the foliar application of $MgSO_4$ improved yield and fruit quality (Zlamalova *et al*., 2015).

Fe and Zn have pivotal role in enzymatic activity, RNA and DNA biosynthesis and in reducing ROS levels in plants (Marschner, 2012). In *Vigna radiata* plants grown under salinity conditions, nano-zinc treatment increased total soluble protein, proline accumulation, total soluble sugar, chlorophyll, carotenoid content, total phenolic and flavonoids content and enzymatic activity (Al-Zahrani *et al.*, 2021). In the study conducted in *Artemisia dracunculus* L., it was found that folioar application with nano-Fe improved the growth and SOD activity in the plant (Hassanpouraghdam *et al*., 2023).

Iran is facing large-scale climate change (decrease in rainfall, heterogeneous rainfall patterns and environmental problems) caused by extensive drying of rivers and lakes have increased salinity stress, which has a detrimental effect on plant growth and yield. Therefore, the study of the methods to combat the destructive effects of salinity with fewer environmental side effects. The aim of this study was to understand the plant behavior (morphological and physiological change) in response to salinity and exogenous methanol, $FeSO_4$, $MgSO_4$ and nano- zinc application. We hoped that foliar application is able to mitigate the salt stress by improving various morphological and biochemical parameters.

Materials and methods

To study the effects of NaCl salinity (0, 50 and 100 mM) and foliar application of $MgSO_4$, $FeSO_4$, nano-zinc and methanol on the growth and some physiological treats of *Coriandrum sativum*; A factorial experiment based on Completely Randomized Design with three replications was arranged at the Research Greenhouse of Azerbaijan Shahid Madani University, Tabriz, Iran during 2020. *Coriandrum sativum* seeds were planted in the medium-sized perlite in pots (5 liters). Light intensity was about 450 µmol m^{-2} s^{-1}, temperature regime; 25 and 18˚C at day and night. After germination, the plants were nourished with Hoagland's nutrient solution (up to 3 leaflets), (EC of 2.1 mS cm^{-1}; pH=5.8). When plats reached to 3 leaflets, salinity treatment was applied (0, 50 and 100 mM) for 8 weeks. One week after salinity treatment, plants were sprayed with: dH_2O (control); $FeSO_4$ and nano-zinc oxide, 3 mg L^{-1} (Vojodi Mehrabani *et al*., 2018b); methanol (10%) (Valizadeh Kamran *et al*., 2019); $MgSO_4$, 1% (Khalaj *et al*., 2020). One week after the first foliar application, the plants were sprayed again with the same treatments. Nano-ZnO was supplied by the US-Nano Company (US Research Nano Materials, Texas, USA). The pH of Hoagland's nutrient was 5.8 and was recorded every day and adjusted by using H_2SO_4 (5% v/v).

Dry weight (biomass): Dry weight was calculated following oven drying at 30˚C until constant weight.

Relative water content (RWC): 0.5 g fresh leaf samples were incubated for 4 h in 100 ml of distilled water. Then, the turgid weight of leaf samples was measured. The leaf samples were packed in paper bags and oven dried (70˚C for 48 h). The RWC was determined by the methods of Xu *et al.* (2006).

Essential oil extraction: 30 g dry leaf sample was extracted by hydrodistillation during 3 h using a Clevenger-type apparatus. The oil content was dried with anhydrous sodium sulfate (Hassanpouraghdam *et al*., 2023).

Minerals analysis: (0.3 g) of dry leaf samples were acid-digested according to the methods described by Chrysargyris *et al*. (2018) and Honarjoo *et al*. (2013). The content of Na and K was quantified by the flame photometric method (Corning, 410, England). N content was measured by the Kjeldahl method. The content of Zn, Ca, Mg and Fe were quantified by atomic absorption spectroscopy (Shimadzu, AA6300, Japan).

Chlorophyll content: Chlorophylls a and b content was quantified by the method of Prochazkova *et al*. (2001). For the measurement of chlorophyll content, leaf samples (0.5 g) were incubated in 5 ml of dimethyl sulphoxide (DMSO) at 65˚C for 4 hrs. Absorbance was recorded at 645 and 665 nm, and chlorophyll a (chl a) and chlorophyll b (chl b) were calculated.

Total soluble solids (TSS): Soluble solids content (TSS) was quantified by a hand refractometer (Erma, Tokyo, Japan) from the extract obtained by squeezing the leaves, and the data are presented as ^{0}Brix.

Proline content: 0.5 g Leaf samples were homogenized in 5 ml of 3% (w/v) sulfosalycylic acid using mortar and pestle. About 2 ml of extract was taken in a test tube and 2 ml of glacial acetic acid and 2 ml of ninhydrin reagent were added. The reaction mixture was boiled in a water bath at 100^{o}C for 30 min. After cooling the reaction mixture, 6 ml of toluene was added and then transferred to a separating funnel. After thorough mixing, the chromophore containing toluene was separated and absorbance was read at 520 nm in spectrophotometer (T80, UK) against toluene blank. Concentration of proline was estimated by referring to a proline standard curve (Fedina *et al*., 2006).

Hydrogen peroxide and lipid peroxidation: Hydrogen peroxide (H_2O_2) content was assessed following the method described previously by Chrysargyris *et al*. (2019). 0.2 g leaf tissue was powdered in liquid N_2, ground in ice-cold 0.1% trichloroacetic acid, and centrifuged at 12,000 g for 15 min. 0.5 mL of the supernatant were mixed with 0.5 mL

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of 10 mM potassium phosphate buffer (pH = 7.5) and 1 mL of 1 M potassium iodide. The H_2O_2 concentration was evaluated using standards of 5 to 1000 µM H_2O_2, and a calibration curve was plotted accordingly. The absorbance of the samples and standards was measured at 390 nm, and the results were expressed as µmol H_2O_2 g^{-1} fresh weight.

A 0.5 to 1.0 g of plant tissue was homogenized in 5 ml of 5% (w/v) trichloro-acetic acid, and the homogenate was centrifuged at 12,000 rpm for 15 minutes at room temperature. The supernatant was mixed with an equal volume of thiobarbitoric acid (0.5% in 20% (w/v) trichloro-acetic acid), and the mixture was boiled for 25 min at 100°C followed by centrifugation for 5 min at 7,500 rpm to clarify the solution. Absorbance of the supernatant was measured at 532 nm and corrected for nonspecific turbidity by subtracting the A600 (Heath and Packer, 1968).

Catalase activity: Catalase enzyme activity was determined according to the methods of Sairam *et al*. (2002). Leaf samples were collected in an ice bucket and brought into the laboratory. Leaves were then washed with distilled water and surface moisture was wiped out. Leaf samples (0.5 g) were homogenized in ice cold 0.1 Mphosphate buffer (pH 7.5) containing 0.5 m Methylenediaminetetraacetic acid (EDTA) with pre-chilled pestle and mortar. The homogenate was transferred to centrifuge tubes and was centrifuged at 4°C in $T80^+$ refrigerated centrifuge for 15 min at 15,000/g. The supernatant was transferred to 30 ml tube for enzyme extract (Sairam *et al*., 2002)**.**

The data were analyzed by SPSS (ver. 15). Means were compared by LSD test.

Results

Aerial parts yield (dry biomass): Aerial parts yield was influenced by the interaction effects of treatments (Table 1). The lowest data belonged to NaCl 100 mM × non-sprayed plants. All foliar application treatments improved the aerial parts yield under non-saline conditions (Table 2). Non-saline condition × Fe spray increased plant biomass up to 50% compared to control plants.

Relative water content: Relative water content (RWC) was influenced by the interaction effects of salinity and foliar spray (Table 1). The top percent of RWC was recorded at no-saline × $FeSO_4$ and Zn spray and NaCl 50 Mm × $FeSO_4$ treatment (Table 2). The results showed that with increasing salinity level (100 mM), the RWC content was reduced and foliar spray under such condition had no effects on improving the RWC content of leaves (Table 2).

Total soluble solids content: Total soluble solid (TSS) content influenced by foliar treatments (Table 1). Methanol (1.1 ^{0}Brix), $FeSO_4$ (1.7 ^{0}Brix) and nano Zn (1.3 ^{0}Brix) foliar spray (1.5 ^{0}Brix) increased TSS content compared to control plants (Table 3).

Chlorophylls a and b: Chlorophyll a and b content were responded to the interaction effects of treatments (Table 1). The results showed that the highest Chlorophyll a content was recorded at non-saline × $FeSO_4$ treatment. Foliar spray with $MgSO_4$, methanol, $FeSO_4$ and Zn under non-salinity increased chlorophyll content in leaves (Figure 1).

Essential oil content: The essential oil content was influenced by the independent effects of salinity and foliar spray (Table 4). The highest oil content belonged to 50 mM salinity treatment (Table 5). Individual effects of foliar treatments increased oil content and $MgSO_4$ and Fe treatments had the highest precept of oil (Table 3).

Proline content: Proline content increased under salinity stress. With salinity of 100 mM, proline content in leaves was increased (91.6 µg g^{-1} FWt) and the least proline content (29.4 µg g^{-1} FWt) was devoted to no-saline treatment (Table 5).

Malondialdehyde (MDA) and H_2O_2 content: Malondialdehyde content was influenced by salinity stress (Table 4), and the top amounts of MDA were

Recorded at 100 mM NaCl treatments that shows 56% increase compared to control plants (Table 5). H_2O_2 content was influenced by independent effects of salinity and foliar applications (Table 4). 100 mM NaCl treatments raise up H_2O_2 content in plants (Table 5). The high recorded amounts of H_2O_2 has belonged to non-foliar treatments (Table 3).

Catalase activity: The highest CAT activity was recorded for NaCl 50 mM × $FeSO_4$ and nano-Zn treatments. The lowest CAT activity recorded for control plants which showed 31% decrease compared to salinity levels of 100 mM (Table 2).

Minerals content: Phosphorus, Ca and Fe content were impacted by the independent effects of treatments (Table 6). K/Na ratio was responded to the sole effects of salinity, and the highest data were recorded at the non-saline condition (Table 5). The highest P content belonged to the no-saline condition (Table 5). Non-salinity condition increased amounts of Ca (43 gKg^{-1}) and Fe (32 $mgKg^{-1}$) in leaves compared to 50 and 100 mM NaCl treatment (Table 5). Foliar treatment with methanol increased P and Ca content in leaves (Table 3). $FeSO_4$ foliar application increased Fe content (36%) compared to control plants (Table 3). N, K, Mg and Zn content were impacted by treatment interactions (Table 6). Methanol, nano- Zn and $FeSO_4$ application × no-salinity improved nitrogen content of plants (Table 7). Methanol foliar treatment × NaCl 50 mM and non-salinity × methanol sprays increased K content in leaves (Table 7). Under non-saline condition with $MgSO_4$ and methanol spray, Mg content was increased (Table 7). The highest Zn content has belonged to no-saline treatments nano-Zn spray (Table 7).

Discussion

Salinity stress induces hyper-osmotic and ion toxicity and adversely impacts the physiological responses of plants. Salinity has direct and indirect effects on photosynthesis, limiting stomatal conductance, ions

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Table 1. Effects of salinity and foliar treatments on *Coriandrum sativum* plants growth and physiological response

Significance	df	Aerial part dry weight	Total soluble solids content	Relative water content	Chlorophyll a content	Chlorophyll b content
Replication	2	18711^{ns}	0.98^{**}	78^{ns}	0.001^{ns}	0.06^{ns}
Salinity (S)	2	74814^{**}	0.57^{ns}	264^{**}	0.4^{**}	0.14^{**}
Foliar (F)	4	19561^{**}	1.8^{**}	315^{**}	0.12^{**}	0.03^{ns}
S × F	8	28749^{**}	0.015^{ns}	418^{**}	0.07^{**}	0.78^{*}
E	28	10015	0.29	18	0.021	0.025

ns: nonsignificant; * Significant difference at P ≤ 5%; ** Significant difference at P ≤ 1%

Table 2. Interaction effect of salinity and foliar applications on some physiological charactrastics of *Coriandrum sativum* plants

NaCl (mM)	foliar	Aerial parts dry weight (g m^{-2})	Relative water content (%)	Catalase activity (units mg^{-1} protein)
0	Control	182^{c}	73^{bc}	36.2^{c}
0	$MgSO_4$	287^{ab}	79^{b}	38.1^{c}
0	Methanol	298^{ab}	79^{b}	41.2^{bc}
0	$FeSO_4$	360^{a}	89^{a}	45.0^{b}
0	Nano-Zn	278^{a}	87^{a}	39.7^{bc}
50	Control	151^{e}	68^{c}	46.2^{b}
50	$MgSO_4$	179^{c}	75^{b}	43.1^{b}
50	Methanol	191^{b}	77^{b}	48.2^{b}
50	$FeSO_4$	210^{b}	81^{a}	52.3^{a}
50	Nano-Zn	184^{c}	79^{b}	56.7^{a}
100	Control	103^{f}	52^{d}	49.6^{b}
100	$MgSO_4$	154^{e}	65^{c}	42.3^{bc}
100	Methanol	165^{d}	63^{c}	47.6^{b}
100	$FeSO_4$	171^{c}	71^{bc}	48.3^{b}
100	Nano-Zn	165^{d}	67^{c}	37.8^{c}

Significant differences among treatments are indicated by different Latin letters

Table 3. Mean comparisons for the effects of foliar application on the growth, physiological responses and elemental content of *Coriandrum sativum*

Foliar application	Total soluble solids content (^{0}Brix)	Essential oil content (%)	H_2O_2 content (µmol g^{-1}FW)	Ca content (g Kg^{-1})	P content (g Kg^{-1})	Fe content (mg Kg^{-1})
Control	0.51^{b}	0.10^{c}	1.43^{a}	1.6^{b}	5.1^{c}	25.1^{b}
$MgSO_4$	0.73^{b}	0.32^{ab}	0.91^{b}	1.3^{c}	6.2^{b}	23.2^{c}
Methanol	1.1^{a}	0.29^{b}	0.78^{c}	2.7^{a}	7.1^{a}	26.4^{b}
$FeSO_4$	1.7^{a}	0.43^{a}	0.65^{c}	1.5^{b}	6.5^{b}	39.6^{a}
Nano-Zn	1.3^{a}	0.21^{b}	0.96^{b}	1.6^{b}	6.8^{b}	23.5^{c}

Significant differences among treatments are indicated by the different Latin letters

homoeostasis, carbon metabolism and water balance (Munns and Tesster, 2008; Al-Zahrani *et al*., 2021). Under salinity stress, nourishment with $FeSO_4$, nano-Zn, $MgSO_4$ and foliar spray with methanol reduced the side-effects of salinity in plants. Methanol, Zn, Fe and $MgSO_4$ plays roles in different physiological activities under salinity stress. The application of macro-micronutrient and methanol have an important role in the defense strategies of the plant as well, in this study, exogenously applied Zn, $FeSO_4$, $MgSO_4$ and methanol improved dry weight and TSS content of plants. Our results are in accordance with the finding of Hassanpouraghdam *et al*. (2019) in *Rosmarinus officinalis* and Elhindi *et al*. (2016 a) in coriander. They reported that salt-stress decreased plant growth, chlorophyll content and enzaymatic activity.

Methanol treatment improves the photosynthetic activity, TSS content and stabilizes cell membranes under saline conditions (Ehyaei *et al*., 2010; Valizadeh Kamran *et al*., 2019). Methanol is feasibly metabolized by the plants and participates in photosynthesis, carbohydrates and amino acids biosynthetic pathways and, improves plant growth and yield (Yazdi Far *et al*., 2015). In line, Yazdi Far *et al*. (2015) reported that in *Calendula officinalis*, the dry weight, number of capitol, phenolics, essential oil content of plants were influenced by Zn and methanol treatments.

Salinity stresses by disturbing chloroplast photochemistry, exceed the rate of absorption and consumption of light energy by photosynthetic pigments and accelerates the photo-inhibition process and decreased photosynthetic ability of plants under salinity stress (Kalaji *et al*., 2018). Photosynthetic ability also increases by the absorption of minerals nutrients. Minerals nutrients are needed for chlorophyll biosynthesis. Zinc and Fe treatment increases plant

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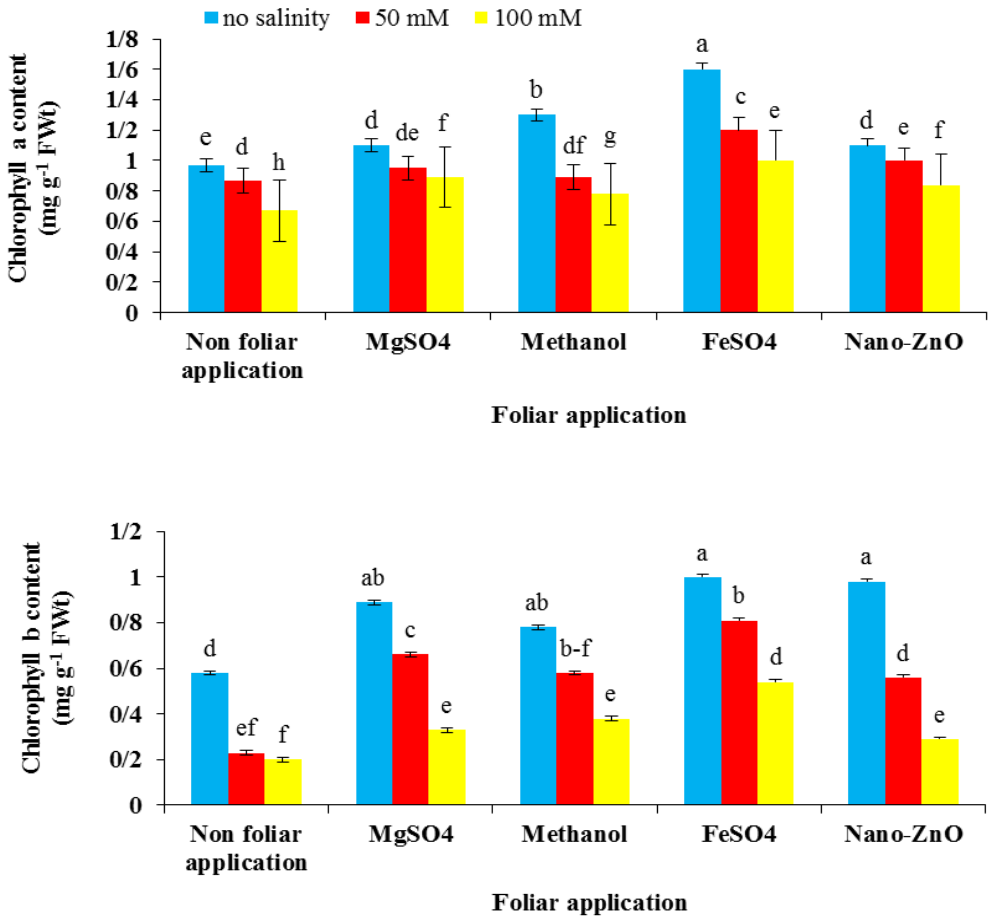


Figure 1. Interaction effect of salinity levels and foliar applications on chlorophyll a and b content of *Coriandrum sativum*. Significant differences among treatments are indicated by different Latin letters

Table 4. Effects of salinity and foliar application on some physiological traits of *Coriandrum sativum*

Significance	df	Essential oil content	Proline content	MDA content	H_2O_2 content	Catalase activity
Replication	2	0.002^{ns}	101^{ns}	4.3^{ns}	13.2^{**}	0.71^{ns}
Salinity (S)	2	1.8^{**}	664^{**}	256^{**}	8.6^{**}	4.2^{**}
Foliar (F)	4	2.6^{**}	101^{ns}	4.9^{ns}	0.59^{**}	0.078^{ns}
S × F	8	0.004^{ns}	57^{ns}	0.28^{ns}	0.16^{ns}	1.9^{**}
E	28	0.002	89	7	0.09	0.21

ns: nonsignificant; *Significant difference at P ≤ 5%; ** Significant difference at P ≤ 1%

Table 5. Mean comparisons for the effects of NaCl salinity on growth and physiological responses of *Coriandrum sativum*

NaCl (mM)	Essential oil content (%)	Proline (µg g^{-1} FWt)	MDA (nmol g^{-1} Fwt)	H_2O_2 (µmol g^{-1} fw)	Na (g Kg^{-1})	K/Na	P (g Kg^{-1})	Ca (g Kg^{-1})	Fe (mg Kg^{-1})
0	0.23^{b}	29.4^{c}	34.1^{c}	1.17^{b}	1.9^{c}	7.6^{a}	6.6^{a}	4.3^{a}	32^{a}
50	0.39^{a}	51.7^{b}	56.3^{b}	1.69^{b}	12.7^{b}	5.6^{b}	4.9^{b}	3.6^{b}	21^{b}
100	0.15^{c}	91.6^{a}	77.4^{a}	2.3^{a}	29.6^{a}	1.2^{c}	4.5^{b}	1.9^{c}	14.2^{b}

Significant differences among treatments are indicated by the different Latin letters

photosynthesis by producing chlorophyll and has crucial role in biomass production (Kalaji *et al.*, 2018; Hassanpour aghdam *et al.*, 2019). Zinc acts as a structural and catalytic component of proteins and enzymes of pigments biosynthesis. Increased chlorophyll contents are due to zinc which acts as, enzymes and as a co-factor for the normal development of pigment biosynthesis (Samreen *et al.*, 2017). The results of the present study also showed that the positive effects of treatments used in this experiments on the chlorophyll content of *C. satavium*.

In the current study, exogenous application of Fe and Zn showed pronounced increases in catalase activity, chlorophyll content, RWC, N and K content

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Table 6. ANOVA for the effects of salinity and foliar applications on *Coriandrum sativum* plants elemental content

Significance	Df	N	P	K	Ca	Mg	Fe	Na	Zn	K/Na
Replication	2	2.6^{ns}	0.0001^{ns}	15^{ns}	1.09^{ns}	0.0004^{ns}	78^{**}	9.6^{**}	9.7^{ns}	7.9^{*}
Salinity (S)	2	2.9^{ns}	0.05^{**}	5.6^{**}	6.2^{**}	0.007^{**}	340^{**}	10.7^{**}	13.2^{ns}	1.3^{**}
Foliar (F)	4	4.6^{**}	0.08^{**}	8.9^{**}	4.8^{**}	0.003^{*}	421^{*}	0.05^{ns}	351^{**}	0.39^{ns}
S × F	8	8.1^{*}	0.001^{ns}	12^{**}	1.3^{ns}	0.019^{**}	0.68^{ns}	0.15^{ns}	97^{**}	0.11^{ns}
E	28	1.4	0.003	0.35	0.9	0.00	10.7	0.07	18.3	0.07

Significant differences among treatments are indicated by the different Latin letters.

Table 7. Interaction effect of salinity and foliar applications on elemental content of *Coriandrum sativum* plants

NaCl (mM)	foliar	N content (g Kg^{-1})	K content (g Kg^{-1})	Mg content (g Kg^{-1})	Zn content (mg Kg^{-1})
0	Control	11.6^{b}	10.1^{b}	0.68^{d}	4.5^{d}
0	$MgSO_4$	12.3^{b}	6.6^{d}	1.6^{a}	3.8^{e}
0	Methanol	13.5^{ab}	13.4^{a}	1.2^{a}	5.3^{c}
0	$FeSO_4$	14.6^{a}	8.4^{c}	0.9^{b}	3.4^{e}
0	Nano-Zn	14.9^{a}	6.9^{bc}	0.85^{b}	9.8^{a}
50	Control	9.3^{c}	8.6^{c}	0.58^{d}	4.2^{d}
50	$MgSO_4$	10.2^{c}	8.1^{c}	0.98^{b}	3.1^{e}
50	Methanol	11.3^{b}	11.5^{a}	0.89^{b}	5.2^{c}
50	$FeSO_4$	12.2^{b}	8.8^{c}	0.78^{c}	3.7^{e}
50	Nano-Zn	11.5^{b}	6.4^{d}	0.65^{d}	8.3^{b}
100	Control	7.1^{d}	5.8^{e}	0.47^{e}	2.6^{f}
100	$MgSO_4$	9.6^{c}	6.1^{d}	0.87^{c}	2.7^{f}
100	Methanol	12.1^{b}	8.3^{c}	0.66^{d}	4.8^{d}
100	$FeSO_4$	11.7^{b}	7.1^{d}	0.53^{d}	3.4^{e}
100	Nano-Zn	9.3^{c}	5.7^{e}	0.56^{d}	4.2^{d}

Significant differences among treatments are indicated by different Latin letters

under non-saline or 50 mM salinity. Similar results were shown under salinity stress in *Vigna radiata* plants under zinc application (Al-Zahrani *et al*., 2021). In the current study, relative water content reduced with increasing salinity stress and foliar treatment with Fe and Zn had positive effects on RWC content under 50 mM salinity. Salinity had negative effects on cell turgor and elongation (Hussein and Abou-Baker, 2018). Salinity in rosemary reduced RWC and cell growth, however, Zn foliar treatment re-directed the RWC and reduced the salinity effects, correspondingly (Hassanpouraghdam *et al.*, 2021).

A cascade of oxidative reactions resulting from the overproduction of ROS was observed in different studies under salinity stress. ROS damage induced lipid peroxidation and reduced proteins polymerization (Tavallali *et al*., 2010; Hassanpouraghdam *et al*., 2019; Vojodi Mehrabani, 2019). Zinc application under salinity stress reduces the deleterious effects of salinity (electrolyte leakage, H_2O_2 content) (Al-Zhrani *et al*., 2021). Under salinity, zinc has a regulatory role on the Na^+ and Cl^- uptake and translocation in plants and even reduced ROS production. Foliar application lowered the H_2O_2 content and lipid peroxidation in the plant (Munns and Tesster, 2008). Wani *et al*. (2013) reported that Zn is indirectly responsible for the increased activity of enzymes (APX, catalase) involved in detoxification H_2O_2. In *Vigna radiata*, catalase activity increased in response to salinity and Zn treatment and increasing catalase activity, by Zn treatment; improving H_2O_2 scavenging during stress (Al-Zahrani *et al*., 2021).

Under salinity, chlorophyll biosynthesis is reduced due to the reduced Fe and Mg absorption and translocation (Hassanpouraghdam *et al*., 2019). In our experiment, a noticeable increase was observed in proline, H_2O_2 and MDA content under salinity. Similar results were reported by Chrysargyris *et al*. (2018) in lavender. Under salinity, over-generating of ROS molecules cause membranes deterioration (Liang *et al*., 2018). Zn plays a crucial role in keeping cell membranes integrity and reducing the side effects of ROS radicals (Hafeez *et al*., 2013). Proline accumulation under stress condition, inhibits toxic ions absorption, maintains cell membranes integrity, and secures energy for cell metabolism (Grattan and Grieve, 1998). Catalase is a key scavenger of H_2O_2 molecules produced by ROS molecules (Munns and Tester, 2008). It has an important role in converting H_2O_2 into H_2O and oxygen (Kang and Saltveit, 2002). Any increase in the CAT activities under salinity conditions, improves the plants withstand against environmental stress (Munns and Tester, 2008). The results of a study on grape showed that Fe application under salinity increased catalase activity. Increasing the activity of antioxidant enzymes such as catalase and SOD during salinity stress in plant**,** plays substantial action in removing free radicals produced in the cell (Aazami *et al*., 2022). Iron has pivotal role in the activity of several enzymes like, catalase, peroxidase, cytochrome and in the biosynthesis of proteins. Cytochromes are proteins

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in the plants and has a prosthetic group contain complex Fe and heme. Other related enzyme are catalase and peroxidase, which their activity greatly declines under iron deficiency. Foliar application of Fe under the salinity conditions meliorate the stress effects by the stimulation of catalase biosynthesis (Marschner, 2012).

Disruption in the absorption and distribution of nutrients due to salinity stress in the plant has frequently been observed. Under NaCl salinity, Na^+ Substitutes Ca^{2+} ions and disrupts the activity of carriers and ionic channels in the root, and leads to partial and/or total blockage of essential nutrients and water absorption in plants (Guo *et al*., 2015). Nutrients imbalance reduces chlorophylls and carotenoids content, photosynthesis activity, impairs plant enzymatic activity, and ultimately detracts the growth and productivity of plants (Neocleous and Vasilakakis, 2007). Improving the potassium content in plants grown under salinity stress, increases the plant's resistance to the stress. Potassium has important roles in metabolic processes such as stomatal actions, cell growth, osmotic regulation, water balance, and enzayme activity (Munns and Tester, 2008). In *Pelargonium graveolens* plant, foliar spray with methanol under salinity improved absorption of Fe, K, and plant dry weight (Vojodi Mehrabani, 2019).

Zn application under salinity greatly improved membranes stability, reduced Na absorption, and ultimately enhanced chlorophyll biosynthesis and plant growth (Tufail *et al.*, 2017).

Essential oils have important roles in the protection of plants against pests, diseases and environmental stressors (Chrysargyris *et al*., 2018; Elhindi *et al*., 2016b). Salinity adversely affects the active metabolites profile of plants. In the study conducted by Vojodi Mehrabani (2019), methanol spray in pelargonium, increased the oil content of plants due to accelerated biosynthesis of phenolics and terpenoid constituents (Gout *et al*., 2000; Valizadeh Kamran *et al*., 2019). Moreover, Mg application increased *Ocimum basilicum* L. oil content (Pazoki *et al*., 2011).

Zn, Methanol, and Mg have predominant functions in photosynthesis (Pazoki *et al*., 2011; Tufail *et al.*, 2017; Vojodi Mehrabani, 2019). Any improvement in phothosyntisis increased glucose generation, and hence the carbon skeleton for the terpenoid compounds biosynthesis (Hafeez *et al*., 2013; Vojodi Mehrabani *et al.*, 2019).

Conclusion

The results showed that salinity stresses negatively affected plant growth and physiological responses of *Coriandrum sativum*. Foliar treatment with methanol increased P and Ca content of plants. $MgSO_4$ and methanol foliar spray enhanced essential oil content. With salinity added up, proline, Na^+, and MDA content were increased. All foliar treatments and no-saline conditions raised up plant dry weight and chlorophyll b content of plants, but chlorophyll content increased at non-saline × $FeSO_4$ treatment. $FeSO_4$ and nano–Zn spray × 50 mM salinity improved catalase activity. $FeSO_4$, nano-Zn and methanol spray × non-saline treatment increased N content of plants. The highest K content has belonged to non-salinity and 50 mM salinity × methanol foliar treatment. According to the response of the measured traits, foliar spray, especially with nanoparticles of zinc and iron sulfate, had the most significant effect in reducing destructive effects of salinity on coriander. The results showed that foliar spray partially reduced the adverse side effects of salinity and the results with some detailed studies would be visible to the pioneer plant producers and possibly extension section.

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