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ENHANCEMENT OF PLANT GROWTH, CHEMICAL COMPOSITION AND SECONDARY METABOLITES OF ESSENTIAL OIL OF SALT-STRESSED CORIANDER (*CORIANDRUM SATIVUM* L.) PLANTS USING SELENIUM, NANO-SELENIUM, AND GLYCINE BETAINE

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ABSTRACT: Two pot experiments were carried out under greenhouse conditions during the two successive winter seasons of 2017/2018 and 2018/2019 to enhance the performance of coriander (*Coriandrum sativum* L.) plants under salt stress conditions (NaCl at 0, 25, 50 and 75 mM). Along with the possibility of enhancing the plant growth, chemical composition, and secondary metabolites of essential oils. Foliar applications of selenium (25 and 50 ppm), nano selenium (25 and 50 ppm), glycine betaine (5 and 10 mM), and distilled water (control treatment) were applied on *C. sativum* plants. The foliage and root growth, chemical composition, and secondary metabolites of essential oils of coriander plants grown under salt stress were examined. The obtained results of the two seasons revealed that salt stress had significant deleterious effects on vegetative growth, fruit yield, essential oil yield, secondary components, and leaves chemical composition, while it enhanced the electrolyte leakage, proline content, Na^+ and Cl^- of the leaves. Generally, the tested treatments: selenium, nano selenium, and glycine betaine varied in their significant effects on the studied characters. Selenium and glycine betaine treatments were more effective in improving coriander plants to salinity stress where they significantly increased almost all the studied parameters under saline compared to the control.

Key words: Coriander, selenium, selenium nanoparticles, glycine betaine, salt stress.

INTRODUCTION

Coriander (*Coriandrum sativum* L.) is one of the valuable medicinal annual herbs that belong to the Umbelliferae (Apiaceae) family (Evans 2002). The fresh leaves and the dried fruits of coriander are the most popular parts used in cooking as flavoring agents. In folk medicine, coriander is used to cure disorders of digestive, respiratory and urinary systems because of its diaphoretic, diuretic, carminative, and stimulant activities (Sahib *et al*., 2013). The essential oil is known for its inhibition activity against Gram-positive and -negative bacteria (Silva *et al*., 2011), yeasts and molds (Soares *et al*., 2012). The essential oil content is up to 1%, and linalool is the main component (Neffati *et al*., 2011). The coriander essential oils content and chemical composition are significantly affected by different factors including genetic (Nejad Ebrahimi *et al*., 2010), cultivation (Zheljazkov *et al*., 2008) as well as the abiotic stress, such as salinity (Neffati and Marzouk 2009).

Salinity stress is an important environmental stress factor that limits agricultural production. It is a global eco-threat to sustainable agriculture and is getting increased with time because of water shortage. According to the latest statistics, 20% of farmland in the world is faced with the salinity problem. Salinity lowers the osmotic potential of soil solution and affects the plant growth through nutritional and hormonal imbalance and induction of oxidative stress, or a combination of these factors (Rahnama *et al*., 2010). It significantly reduces the ability of plants to take up water causing a reduction in plant growth, ineffectiveness of stomata closure, inhibition of photosynthesis mechanism, imbalance in nutrient concentrations in the plant tissues, and yield reduction (Elhindi *et al*., 2016).

One strategy to increase tolerance of plants including coriander against salinity is the utilization of several compatible solutes such as selenium (Se), nano-selenium (nano-Se), and glycine betaine (GB). Selenium, a non-essential element for plants, many studies have shown that at low concentrations of Se exerts beneficial effects on the growth and stress tolerance of plants by enhancing their antioxidative capacity (Kaur and Nayyar, 2015). Also, Se might improve salt tolerance, transpiration rate, decline the osmotic potential, uphold turgor or the activity of antioxidant enzymes, stimulate the accumulation of free amino acids and total soluble sugars, and enhance the plant growth (Nawaz *et al*., 2015). In soil, selenate and selenite are the main sources of Se and may be efficiently uptake by plants (Liu *et al*., 2017).

Moreover, the nano-forms of minerals are characterized by unique physicochemical characteristics by which triggering especial responses differ from that of the bulk type (Asgari-Targhi *et al*., 2018). Nano- selenium could be used as an additional fertilizer for improving the productivity of crops. Thus, it was recorded that there is a good opportunity for the mediation of selenium nanotechnology in the area of plant nutrition and fertilizers (Mastronardi *et al*., 2015).

Alongside, glycine betaine is an amino acid derivative that accumulates in plant cells (Chen and Murata, 2002). Exogenous application of glycine betaine on the leaves or roots could be used to ameliorate plant abiotic stress (Kanechi *et al*., 2013). Foliar application of glycine betaine reduced the adverse effects of abiotic stresses by detoxification of reactive oxygen species, altering cellular osmotic, and protecting membrane integrity (Ahmad *et al*., 2012 and Hayat *et al*., 2012). Glycine betaine might also protect membrane functions from high concentrations of Na^+ and Cl^- (Rhodes *et al*., 1989). Several reports demonstrated the positive effects of foliar application of glycine betaine on plant growth and final crop yield under salt stress such as in lettuce (Mostafakamal *et al*., 2016). Therefore, the current research was designed to investigate the response of growth, yield, essential oil yield and biochemical constituents of coriander after the foliar applications of selenium, nano-selenium, and glycine betaine under salt stress conditions.

MATERIALS AND METHODS

Experimental design:

During the winter seasons of 2017/2018 and 2018/2019, two pot experiments were carried out under greenhouse conditions at the farm of Faculty of Agriculture, Damanhour University, El-Beheira Governorate, Egypt. The coriander uniform seeds of cv. Balady were sown on 20th October in both seasons in plastic pots (30 cm diameter and 35 cm height), filled with 8.5 kg of sandy loam soil, and placed under greenhouse condition. After 15 days the seedlings were thinned to three uniformed seedlings in each pot.

Before seed sowing, soil samples were collected, and the physicochemical characteristics of the soil were determined according to the methods described by Jackson (1967) in both seasons (Table 1). The soil characteristic analyses were carried out at the Natural Resources and Agriculture Engineering Department, Faculty of Agriculture, Damanhour University.

The experimental design was a split-plot in a randomized complete block design, the saline water at 0, 25, 50 and 75 mM of NaCl represented in the main plots whereas, the foliar application of selenium at 25 and 50 ppm, nano selenium at 25 and 50 ppm, glycine betaine at 5 and 10 mM and distilled water as a control treatment were randomly arranged in sub-plots. Each treatment was composed of five pots replicated three times with three plants for each pot. The study involved 20 treatments representing the combinations of four saline water and five treatments of foliar applications.

On November 11, (twenty-one-day old) uniformal plants of coriander were prepared for treatments. The plants were treated with saline water as a drench soil with 5 days interval throws the plant life. The value drench was 500 ml per pot. The treatments with selenium, nano-selenium, and glycine betaine were applied twice as a spray application; the first one was carried out on the same day of irrigation with saline water and the second one was applied 15 days later. Spray application was conducted in the morning, and after the spray application, plants were irrigated at the end of the day. The soil surface was covered with polyethylene before the application of selenium, nano-selenium, and glycine betaine to avoid the falling of spray drips on the growing medium. The tested treatments were applied using a hand sprayer (capacity 2 liter) and non-ionic surfactant tween 80 at 0.05% (v/v) was added to all concentrations to decrease the surface tension and increase the content angle of sprayed droplets. Each pot was sprayed individually, and the foliage of plant was moistened until the point of runoff. All the agricultural practices for coriander were applied according to the recommendation of the ministry of agriculture.

Preparation of selenium nanoparticles:

Selenious acid (0.04 mM) under stirring was mixed with glutathione concentration as 0.2 mM and 200 mg bovine albumin solution in 100 ml deionized water. The pH of the mixture was adjusted to 7.2 with 1.0 M sodium hydroxide to initiate the reaction. The reaction lasted one hour under sonication condition, during which the red elemental Se and oxidized glutathione (GSSG) formed. The red solution was dialyzed against redistilled water for 96 h with the water changing every 24 h to separate GSSG from Nano-Se (Huang *et al.*, 2003; El-Batal *et al.*, 2012).

Data recorded:

1. Plant growth characteristics:

After 45 days from seed sowing, five plants from each treatment in each replicate

Table 1. Some physical and chemical properties of the experimental soil during both seasons of 2017/2018 and 2018/2019.

Physical properties						
Season	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Texture**	**Bulk density (g cm^{-3})**	**$CaCO_3$ (%)**
2017/2018	74.53	22.27	3.20	Sandy loam	1.56	2.40
2018/2019	74.65	21.79	3.56	Sandy loam	1.58	2.41
Chemical properties						
Season	**pH**	**EC (dSm^{-1})**	**Organic matter (%)**	**N (ppm)**	**P (ppm)**	**K (ppm)**
2017/2018	7.84	0.86	0.88	43.34	14.12	34.15
2018/2019	7.86	0.91	0.92	51.62	15.13	36.20

were randomly chosen and tagged to be used for data collection about the vegetative growth traits, namely; plant height, leaf length, herb fresh weight, root fresh weight and total fresh weight (g)/plant.

2. Chemical measurements and analyses:

Total leaf chlorophyll content (SPAD index) **w**as measured using a SPAD-502 chlorophyll meter device (Konica Minolta, Kearney, NE, USA) according to Yadava (1986). The contents of ascorbic acid “vitamin C” (mg/100 g) were determined according to the method described by Singh (1988). Free proline content was determined in leaf fresh weight according to Bates *et al*. (1973). Electrolyte leakage was used to assess if the cell membranes were stable or not. It was measured according to the method explained by Lutts *et al*. (1999). Mineral analysis, total N in dry leaves were determined by the Kjeldahl method as described by Jones (1991). The contents of K, P, Ca, Na and Cl were determined according to the methods described by Cottenie *et al*. (1982).

3. Fruits essential oil content and its components:

Coriander plants were harvested in both seasons at full fruits maturity stage. The fruits for each plant were harvested separately and weighed as grams per plant. The fruits were used to estimate the essential oil yield according to the method of Guenther (1961). The essential oil was extracted from coriander fruits using a Clevenger apparatus.

4. Gas Chromatography-Mass Spectrum analysis (GC-MS) of essential oil constituents:

The essential oil of coriander fruits extracted from control treatment (0 mM NaCl) and control treatment sprayed with 10 mM glycine betaine and 50 ppm selenium in both seasons were identified using Agilent gas chromatography coupled with mass spectrometry (GC-MS). The sample was dissolved in hexane and injected at 250 °C (injector temperature) into a capillary column type HP-5 (30 m X 0.25 mm i.d, 0.25 µm film thickness), using helium as a carrier gas at a flow rate of 1 ml/min. The injected volume was 1 µl and the injection mode used was the splitless mode. The oven temperature was raised from 35 °C (hold for 3 min) to 240 °C at the rate of 5 °C/min, then at the rate of 3 °C/min, raised to 280 °C, hold for 3 min. The interface temperature was 250 °C; the ion source temperature was 200 °C. The start time was 4 min and the end time was 61.33 min. The mass and scan range was set at *m/z* 35-800. Components of essential oils were identified by their retention time and matching of the mass spectra with those of NIST and Wiley libraries database.

Statistical analysis:

All obtained data were statistically analyzed by Statistical Analysis Systems (Costat, 2008) and significant means were compared by the Tukey's test at 0.05 probability.

RESULTS AND DISCUSSION

Plant growth characters:

The data showing the main effects of the two studied factors (different salinity concentrations and different levels of “selenium, nano-selenium, and glycine betaine”) and their interactions on plant growth of coriander plants during the two growing seasons of 2017/2018 and 2018/2019 were presented in Tables (2 and 3). Regarding the main effect of salt stress on plant growth parameters, data in Table (2) showed that plant height, leaf length, herb fresh weight, root fresh weight and total fresh weight of coriander plants were significantly decreased with increasing level of NaCl up to 75 mM in both seasons. The greatest reduction of plant growth parameters was obtained under the highest concentration of NaCl “75 mM” in both seasons. Under high concentration of NaCl stress the estimated decuction percentages in plant height, leaf length, herb fresh weight, root fresh weight, and total fresh weight were 46.33 and 46.77, 19 and 23.46, 60.93 and 41.32, 50.46 and 31.40, and 59.87

Table 2. The main effect of different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on plant growth parameters of coriander plants during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Saline water	Plant height (cm)		Leaf length (cm)		Herb fresh weight (g)/plant		Root fresh weight (g)/plant		Total fresh weight (g)/plant	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
					Salt stress					
0 mM	52.88 A	50.93 A	19.05 A	20.50 A	10.06 A	9.22 A	1.09 A	1.72 A	11.14 A	10.94 A
25 mM	44.33 B	43.75 B	18.43 A	19.54 B	7.35 B	8.13 B	0.91 B	1.52 B	8.26 B	9.65 B
50 mM	36.05 C	35.00 C	16.86 B	17.18 C	5.83 C	6.96 C	0.66 C	1.35 C	6.49 C	8.31 C
75 mM	28.38 D	27.11 D	15.43 C	15.69 D	3.93 D	5.41 D	0.54 D	1.18 D	4.47 D	6.59 D
					Selenium, nano-selenium, and glycine betaine					
Control	35.42 D	34.55 E	15.8 3C	13.60 D	4.48 E	5.22 E	0.43 D	1.35 E	4.91 E	6.57 E
Se 1	39.88 C	39.25 C	17.25 B	20.13 B	5.15 DE	6.80 C	0.54 C	1.42 D	5.69 D	8.22 C
Se 2	42.13 B	41.15 B	18.83 A	21.28 A	7.85 B	8.02 B	0.60 C	1.50 C	8.45 B	9.51 B
Nano-Se 1	38.63 C	37.58 D	17.17 B	15.58 C	6.55 C	6.02 D	0.57 C	1.27 F	7.11 C	7.29 D
Nano-Se 2	39.17 C	36.94 D	14.33 D	15.66 C	5.24 D	6.04 D	0.42 D	1.26 F	5.65 D	7.30 D
GB 1	42.50 B	41.35 B	18.75 A	19.65 B	9.38 A	10.04 A	1.59 A	1.70 A	10.97 A	11.74 A
GB 2	45.17 A	43.58 A	19.92 A	21.68 A	8.90 A	9.88 A	1.43 B	1.59 B	10.33 A	11.47 A

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test (*P* ≤ 0.05); n = 3; Means with the same capital letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

and 39.76 compared to the control treatment for the first and second seasons, respectively.

The reduction in the plant growth characters as a result of salinity might be attributed to the accumulation of the salts in the soil, which increased the osmotic pressure of tissue cells and decreased the water absorption and/or redistribution of minerals and utilization (Mazher *et al.*, 2006). In turn, it causes a reduction in cambium activity and maturation of smaller cell size (Wareing and Phillips, 1974). Also, increased salinity could reduce the endogenous level of IAA which may be critical to water movement through the root system of plants (Dunlap and Binzel 1996). The obtained results were in harmony with those reported by Langroudi and Sedaghathoor (2012) on *Rosmarinus officinalis* L.

Concerning the main effect of different rates of selenium, nano-selenium, and glycine betaine on the plant growth parameters, data in Table (2) indicated that spraying the coriander plants with these substances significantly increased plant growth parameters as compared to control in both seasons. However, the differences between control and nano-selenium treatment were the same in fresh weight in both seasons. The results, generally, showed that the highest values of plant height, leaf length, herb fresh weight, root fresh weight, and total fresh weight were recorded with glycine betaine treatments either with 10 or 5 mM, respectively.

Generally, it could be pointed out that exogenous glycine betaine application might counteract the negative effects of high salinity on plant growth by maintaining osmotic adjustment (Ashraf and Foolad, 2007), and stabilizing many functions in the plants' cells, such as the oxygen-evolving PS-II complex (Harinasut *et al.*, 1996), membranes quaternary structures of complex proteins (Murata *et al.*, 1992) and enzymes such as rubisco. Habib *et al.* (2012) reported that the growth improvement due to glycine betaine could be related to high accumulation of K, Ca and tissue glycine betaine, maintenance of high K/Na ratio and

Table 3. The interaction effect between different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on plant growth parameters of coriander plants during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Salinity concentrations	Trts.	Plant height (cm)		leaf length (cm)		Herb fresh weight (g)/plant		Root fresh weight (g)/plant		Total fresh weight (g)/plant	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
0 mM	**Control**	49.33 cd	46.03 d	18.67 a-g	20.40 b-f	7.86 c	7.40 d-f	0.84 f	1.78 cd	8.70 de	9.18 d-f
	Se 1	52.00 bc	49.50 c	16.67 f-j	21.13 bc	6.95 c-f	7.94 c-e	0.74 fg	1.71 d	7.68 d-h	9.64 c-e
	Se 2	53.17 b	51.67 bc	20.00 a-d	21.33 ab	13.31 a	8.89 c	0.76 fg	1.71 d	14.07 ab	10.59 c
	Nano-Se 1	50.67 bc	50.50 bc	18.33 b-h	18.83 ef	10.18 b	6.60 fg	0.85 f	1.35 h-j	11.03 c	7.95 f-h
	Nano-Se 2	51.67 bc	50.67 bc	18.67 a-g	20.27 b-f	6.76 c-f	6.11 f-h	0.65 gh	1.39 g-i	7.41 e-i	7.50 gh
	GB 1	56.00 a	53.17 ab	20.33 a-c	20.13 b-f	13.31 a	14.24 a	2.00 a	2.14 a	15.31 a	16.38 a
	GB 2	57.33 a	55.00 a	20.67 ab	21.37 ab	12.04 a	13.37 a	1.75 b	1.95 b	13.80 b	15.31 a
25 mM	**Control**	40.33 g	40.00 f	16.33 g-k	14.83 g	5.40 f-h	6.23 f-h	0.47 i-k	1.38 hi	5.87 i-k	7.61 gh
	Se 1	43.50 f	44.83 de	17.67 c-i	20.53 b-f	6.34 c-f	7.18 ef	0.69 f-h	1.48 e-g	7.03 f-i	8.67 e-g
	Se 2	45.33 ef	45.60 d	21.33 a	21.87 ab	7.68 cd	8.60 cd	0.73 fg	1.57 e	8.41 d-g	10.17 cd
	Nano-Se 1	43.50 f	42.17 ef	19.33 a-f	18.40 f	6.31 c-f	6.37 fg	0.69 f-h	1.34 h-j	7.01 f-i	7.71 gh
	Nano-Se 2	43.67 f	42.60 ef	15.67 h-k	18.97 c-f	5.57 fg	6.56 fg	0.54 hi	1.36 h-j	6.11 h-j	7.92 f-h
	GB 1	46.33 ef	44.73 de	17.67 c-i	18.90 d-f	10.47 b	11.20 b	1.70 b	1.82 c	12.17 c	13.02 b
	GB 2	47.67 de	46.33 d	21.00 ab	23.30 a	9.69 b	10.75 b	1.52 c	1.69 d	11.20 c	12.44 b
50 mM	**Control**	30.67 jk	30.67 i	14.67 jk	11.57 h	3.19 ij	4.52 i	0.28 l-o	1.19 l	3.46 m	5.71 ij
	Se 1	35.67 hi	34.83 gh	17.00 e-j	19.80 b-f	4.69 g-i	6.43 fg	0.39 i-m	1.26 j-l	5.08 j-l	7.69 gh
	Se 2	38.33 gh	37.00 g	18.67 a-g	21.03 b-d	6.47 c-f	8.32 c-e	0.48 ij	1.42 f-h	6.95 g-i	9.75 c-e
	Nano-Se 1	35.00 i	33.50 h	16.33 g-k	14.40 g	5.93 e-g	6.14 f-h	0.46 i-k	1.32 h-j	6.40 h-j	7.46 gh
	Nano-Se 2	35.67 hi	32.20 hi	14.67 jk	13.43 g	5.57 fg	7.02 e-g	0.30 k-n	1.34 h-j	5.87 i-k	8.35 e-g
	GB 1	36.33 hi	36.83 g	17.33 d-j	18.53 f	7.63 cd	8.16 c-e	1.40 cd	1.49 ef	9.03 d	9.66 c-e
	GB 2	40.67 g	40.00 f	19.33 a-f	21.50 ab	7.33 c-e	8.13 c-e	1.28 de	1.42 f-h	8.61 d-f	9.56 c-e
75 mM	**Control**	21.33 m	21.50 l	13.67 k	7.60 i	1.47 k	2.74 j	0.13 o	1.05 mn	1.60 n	3.79 k
	Se 1	28.33 k	27.83 j	17.67 c-i	19.07 c-f	2.61jk	5.64 g-i	0.35 j-m	1.22 kl	2.96 mn	6.86 hi
	Se 2	31.67 j	30.33 i	15.33 ijk	20.90 b-e	3.94 h-j	6.25 f-h	0.44 i-l	1.29 i-k	4.38 k-m	7.54 gh
	Nano-Se 1	25.33 l	24.17 k	14.67 jk	10.67 h	3.75 ij	4.95 hi	0.26 m-o	1.08 m	4.01 lm	6.03 ij
	Nano-Se 2	25.67 l	22.30 kl	8.33 l	9.98 h	3.05 j	4.45 i	0.17 no	0.97 n	3.22 m	5.42 j
	GB 1	31.33 j	30.67 i	19.67 a-e	21.03 b-d	6.13 c-g	6.56 fg	1.25 de	1.34 h-j	7.39 e-i	7.90 f-h
	GB 2	35.00 i	33.00 hi	18.67 a-g	20.57 b-f	6.54 c-f	7.26 ef	1.18 e	1.31 i-k	7.72 d-h	8.57 e-g

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test ($P \leq 0.05$); n = 3; Means with the same small letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

low accumulation of Na and Cl in the leaves. The obtained results of glycine betaine are in agreement with Agboma *et al*. (1996) on tobacco.

In parallel, selenium plays a critical role in the tolerance against some environmental stress, like acting as an antioxidant, alleviating oxidative stress (Mozafariyan *et al*., 2016). Also, it may be involved in the efficiency of the photosynthetic machinery, alleviating the chlorophyll degradation and preserving the chloroplast ultrastructure (Jiang *et al*., 2017). Moreover, selenium-treated plants have increased proline content (Djanaguiraman *et al*., 2010). The aforementioned results of selenium are in good accordance with those postulated by Diao *et al*. (2014) on tomato.

The effect of the interaction between the different concentrations of salinity and rates of “selenium, nano-selenium, and glycine betaine” on plant growth characters was significant during both seasons (Table 3). The statistical analysis, generally, revealed that the highest values of plant height, herb fresh weight, root fresh weight and total fresh weight of coriander plants were achieved when spraying of coriander plants with glycine betaine under 0 mM salinity in both seasons. On the other hand, the highest values of leaf length were achieved at the combined treatment of 25 mM salinity and either 50 ppm selenium for the first season or 5mM glycine betaine in the second season. Moreover, the application with glycine betaine or selenium under salt stress showed better performance in reducing the salinity adverse effect on vegetative growth of coriander, compared to the control and nano-selenium treatments.

Chemical measurements and analyses:

SPAD index, ascorbic acid, proline content, and electrolyte leakage:

Regarding the main effect of salt stress on SPAD index, ascorbic acid content, proline content, and electrolytic leakage of coriander plants, the obtained results in (Table 4) showed that SPAD index and ascorbic acid content were significantly

Table 4. The main effect of different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on SPAD index, ascorbic acid, proline content and electrolyte leakage of coriander plants during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Saline water	SPAD index		Ascorbic acid (mg/100g)		Proline (mg/g)		Electrolyte leakage (%)	
	1st	2nd	1st	2st	1nd	2nd	1st	2nd
				Salt stress				
0 mM	41.20 A	42.26 A	49.19 A	49.03 A	45.76 D	45.64 D	17.73 C	17.71 D
25 mM	40.31 AB	39.38 B	42.17 B	40.57 B	56.03 C	57.96 C	20.42 C	21.80 C
50 mM	41.08 AB	37.84 C	37.11 C	36.61 C	62.46 B	62.40 B	28.41 B	29.46 B
75 mM	40.00 B	37.99 C	35.88 D	36.08 C	69.21 A	67.89 A	41.46 A	39.03 A
				Selenium, nano-selenium, and glycine betaine				
Control	38.85 B	36.57 C	37.48 D	35.88 C	61.40 A	64.18 A	33.12 A	31.72 A
Se 1	41.84 A	40.16 AB	42.24 AB	41.20 AB	53.22 C	54.58 D	24.85 C	23.94 D
Se 2	41.67 A	40.32 AB	41.02 BC	42.58 A	56.30 B	53.63 D	25.32 BC	22.30 E
Nano-Se 1	40.58 AB	37.83 C	40.30 C	40.15 B	58.26 B	58.64 C	26.24 BC	28.63 B
Nano-Se 2	39.56 AB	38.65 BC	42.29 AB	40.22 B	63.46 A	62.34 B	28.26 B	31.19 A
GB 1	40.87 AB	40.77 A	41.12 BC	41.37 AB	57.56 B	57.56 C	25.04 C	25.04 CD
GB 2	41.26 A	41.28 A	43.14 A	42.59 A	58.39 B	58.37 C	26.19 BC	26.19 C

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test ($P \leq 0.05$); n = 3; Means with the same capital letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

decreased with increasing level of salinity up to the highest concentration in both seasons. On the other hand, proline content and electrolytic leakage were significantly increased with increasing levels of salinity in both seasons. The estimated percentages decrease of SPAD index and ascorbic acid content were 2.91 and 10.1 and 27.06 and 26.41%, for the first and second season, respectively. The estimated percentages of increase in proline content and electrolytic leakage were 51.25 and 48.75 and 133.84 and 120.38% as compared to the control treatment for the first and second season, respectively.

The reduction of chlorophyll contents under salt stress was related to the rapid maturing of leaves (Yeo *et al*., 1991). Also, swelling of thylakoids was induced at the early stage of the damage when plants are affected by salinity and leads to a reduction in chlorophyll synthesis (Yamane *et al*., 2003). It might be due to ion accumulation and functional disorders observed during the stoma opening and closing under salinity stress (Molazem *et al*., 2010). The net photosynthesis, transpiration rate, and stomatal conductance were significantly affected by salinity due to changes in chlorophyll content and chlorophyll fluorescence, damage of photosynthetic apparatus and chloroplast structure (Baki *et al*., 2000, Fidalgo *et al*., 2004). The obtained results are in harmony with those reported by Heidari (2012) on basil.

Ascorbic acid or vitamin C is a small, water-soluble, antioxidant molecule that acts as a primary substrate in the cyclic pathway of enzymatic detoxification of H_2O_2 (Beltagi, 2008). Decreased ascorbic acid content under salt stress has also been reported by Seth *et al*. (2007) on wheat and Emam and Helal (2008) on *Linum usitatissimum* plants. According to these studies, a decrease in ascorbate content might be one of the reasons why salinized coriander seedlings were unable to tolerate salt stress.

Electrolyte leakage was enhanced with increasing salinity levels as compared to the control. This phenomenon was already observed by several authors Hu *et al*. (2013) on melon and Khan *et al*. (2013) on cucumber. The increase in proline content with increasing salt stress is one of the defense mechanisms in which stressed plants used to reduce cell osmotic potential, which resulted in increasing cell water uptake with concomitant increases in both cell turgidity and its activity (Khalil and El-Noemani 2012). These results seemed to be in agreement with those reported by Heidari and Akbari (2012) on two marigold genotypes and Kaya *et al*. (2013) on maize.

Concerning the main effect of different rates of selenium, nano-selenium, and glycine betaine on SPAD index, ascorbic acid, proline content and electrolyte leakage of coriander plants, data in Table (4) indicated that treated-coriander plants had significantly increased SPAD index and ascorbic acid and decreased proline and electrolyte leakage compared to control (spraying with tap water) in both seasons. The highest mean value of SPAD index was observed at 25 or 50 ppm selenium and 10 mM glycine betaine in the first season and 5 or 10 mM glycine betaine in the second season compared to other treatments. The highest mean values of ascorbic acid were observed at 10 mM glycine betaine in both seasons and 50 ppm selenium in the second season only. Also, the highest mean value of proline content and electrolyte leakage was observed at control treatment in both seasons and 50 ppm nano selenium in the first season for proline and the second season for electrolyte leakage. But, the lowest mean values of proline content were observed at 25 ppm selenium in both seasons and 50 ppm selenium in the second season and the lowest mean values of electrolyte leakage were observed at 25 ppm selenium and 5 mM glycine betaine in the first season and 50 ppm selenium in the second season.

Results of selenium foliar application on ascorbic acid content in coriander plants indicated that the incremental rise in the selenium dosage to the coriander plants led to the synthesis of ascorbic acid. Our findings were in agreement with those reported by Ríos *et al*. (2008) who found that ascorbic acid content in lettuce leaves increased gradually with increasing selenium supplied to the plants, via foliar spray or fertigation. Also, the increment of ascorbic acid under glycine betaine foliar application was reported by Shams *et al*. (2016) on lettuce.

Selenium application decreased significantly the electrolyte leakage of salt stress indicating its important role concerning membrane integrity in coriander seedlings. A decrease in electrolyte leakage in response to increasing selenium treatments was also observed by Kong *et al*. (2005) in salt-tolerant sorrel seedlings; they reported that the reduced electrolyte leakage may be a direct consequence of selenium treatment. Glycine betaine exogenous application reduces oxidative damage caused by salt stress and helped to reduce electrolyte leakage. Similar findings were reported in many earlier studies Kaya *et al*. (2013) on maize.

Leaf proline concentrations were significantly decreased due to the foliar application of glycine betaine. Likewise, Heuer (2003) and Demiral and Türkan (2006) also indicated that exogenously applied glycine betaine significantly reduced the proline content in salt-stressed tomato and rice plants, respectively. The reduction in proline content due to foliar application of glycine betaine might be due to the interference of glycine betaine in the process of osmotic adjustment by proline accumulation. Regarding the effect of selenium on proline content, it was recorded by Al-Kazzaz (2018) who indicated that there was a significant decrease in the proline content in broad bean plants by increasing selenium from 0 to 20 mg/l. However, lower proline content of selenium treated plants under salinity suggests that they were less strained due to some ameliorating mechanisms.

Glycine betaine exogenous application improved the availability of advantageous ions like Mg^{++} and K^{+}, and reduced the uptake of injurious ions such as Na^{+} and Cl^{-}, resulting in an increased photosynthetic capacity (Shaddad, 1990). Makela *et al*. (1998 and 1999) reported that the enhancement of photosynthesis after glycine betaine application under salinity conditions may be due to the reduction of photorespiration rate, greater gas exchange and higher carbon availability for photosynthesis. The obtained results are in agreement with Saeed *et al*. (2016) on okra. On the other hand, Diao *et al*. (2014) reported that selenium alleviates salt-induced stress in tomato seedlings by regulating the antioxidant defense systems in the chloroplasts which are associated with the improvement of the photochemical efficiency of PSII.

The effect of the interaction between the different salinity concentrations and different rates of selenium, nano-selenium, and glycine betaine on SPAD index, ascorbic acid, proline content and electrolytic leakage of coriander plants was significant during both seasons (Table 5). The statistical analysis, generally, revealed that the highest values of SPAD index and ascorbic acid were recorded at the combined treatments of control and foliar spray with 25 ppm selenium in both seasons or 5 and 10 mM glycine betaine in the first season for SPAD index. The lowest values of the electrolytic leakage percentage and proline of coriander leaves had been obtained under glycine betaine treatment with the lowest salinity (0 mM NaCl), while the highest values of those measurements were observed for control treatment with the highest salinity concentration (75 mM NaCl).

Leaves mineral content:

Pertaining to the main effect of salt stress on leaves minerals content of coriander plants, the gained results presented in Table (6) showed that there was a positive relationship between Na^{+} and Cl^{-} content and increasing NaCl concentrations. As NaCl

Table 5. The interaction effect between different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on SPAD index, ascorbic acid, proline content and electrolyte leakage of coriander plants during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Salinity concentrations	Trts.	SPAD index		Ascorbic acid (mg/100g)		Proline (mg/g)		Electrolyte leakage (%)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
0 mM	Control	40.47 a-c	42.37 a-d	46.20 c-e	44.53 c	46.74 kl	47.68 jk	16.96 j	17.25 m-p
	Se 1	43.77 a	46.17 a	51.30 a	51.30 a	41.35 m	44.71 kl	18.19 ij	15.36 op
	Se 2	39.77 a-d	44.64 ab	50.99 ab	50.14 ab	43.02 lm	42.13 l	17.64 ij	15.05 p
	Nano-Se 1	40.07 a-c	40.57 b-h	48.30 a-d	47.66 b	50.05 jk	47.35 k	17.77 ij	21.07 i-k
	Nano-Se 2	40.77 a-c	41.40 b-g	47.78 b-d	49.79 ab	52.07 j	50.50 j	20.12 g-j	21.96 i-k
	GB 1	43.33 a	40.20 b-h	49.31 a-c	49.31 ab	43.50 lm	43.53 l	16.94 j	16.94 n-p
	GB 2	43.77 a	40.47 b-h	50.45 ab	50.45 ab	43.56 lm	43.58 l	16.34 j	16.34 n-p
25 mM	Control	40.00 a-c	36.20 hi	43.62 ef	40.96 d-f	57.59 f-i	63.23 ef	24.26 f-i	24.90 g-i
	Se 1	40.13 a-c	39.51 c-i	45.18 d-f	41.19 c-e	53.67 h-j	55.95 hi	18.29 ij	19.27 k-n
	Se 2	40.57 a-c	40.55 b-h	39.25 hi	43.73 cd	52.98 ij	54.27 i	19.76 h-j	18.53 l-o
	Nano-Se 1	42.27 a-c	39.43 c-i	38.77 hi	38.44 f-i	53.87 h-j	56.86 hi	20.15 g-j	23.27 h-j
	Nano-Se 2	39.13 a-d	39.90 b-h	46.40 c-e	38.27 f-i	61.45 ef	62.73 ef	19.82 h-j	25.98 gh
	GB 1	39.63 a-d	39.63 c-h	39.20 hi	39.53 e-h	54.33 g-j	54.33 i	20.24 g-j	20.25 j-m
	GB 2	40.47 a-c	40.47 b-h	42.73 fg	41.89 d-f	58.32 f-h	58.32 gh	20.40 g-j	20.43 i-k
50 mM	Control	37.20 cd	31.07 j	31.39 j	29.92 j	66.61 cd	68.47 bc	36.08 cd	37.57 c
	Se 1	42.07 a-c	37.03 f-i	36.46 i	35.56 i	57.17 f-i	56.93 hi	25.14 f-h	24.43 g-i
	Se 2	42.57 ab	38.55 c-i	37.73 hi	38.40 f-i	61.19 ef	57.11 hi	26.87 ef	25.29 gh
	Nano-Se 1	37.70 b-d	36.55 g-i	37.66 hi	37.32 g-i	58.62 fg	63.35 ef	26.41 e-g	32.67 ef
	Nano-Se 2	43.50 a	37.15 e-i	38.25 hi	36.80 g-i	67.92 b-d	65.22 de	32.17 de	34.04 de
	GB 1	41.97 a-c	41.97 a-e	38.16 hi	38.16 f-i	63.80 de	63.80 ef	27.17 ef	27.19 g
	GB 2	42.57 ab	42.57 a-c	40.09 gh	40.09 e-g	61.87 ef	61.90 f	24.92 f-h	25.02 g-i
75 mM	Control	34.87 d	36.63 g-i	28.72 j	28.11 j	74.65 a	77.33 a	55.17 a	47.17 a
	Se 1	41.40 a-c	37.93 c-i	36.03 i	36.76 g-i	60.69 ef	60.73 fg	37.80 b-d	36.69 cd
	Se 2	40.20 a-c	37.55 d-i	36.11 i	38.06 f-i	68.01 b-d	61.01 fg	37.00 b-d	30.34 f
	Nano-Se 1	42.27 a-c	34.77 ij	36.47 i	37.20 g-i	70.49 a-c	67.00 cd	40.60 bc	37.50 c
	Nano-Se 2	34.83 d	36.17 hi	36.73 hi	36.00 hi	72.40 ab	70.92 b	40.93 bc	42.78 b
	GB 1	41.37 a-c	41.27 b-g	37.79 hi	38.46 f-i	68.57 bc	68.57 bc	35.76 cd	35.78 cd
	GB 2	41.62 a-c	41.63 a-f	39.28 hi	37.94 f-i	69.64 bc	69.67 bc	42.93 b	42.95 b

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test ($P \leq 0.05$); n = 3; Means with the same small letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

concentrations increased the leaf content of Na^+ and Cl^- were increased too. On the other hand, there was a clear negative relationship between N, P, K^+, Ca^{2+} and Mg^{2+} content and NaCl concentrations. As NaCl concentrations increased, the leaf content of N, P, K^+, Ca^{2+} and Mg^{2+} were decreased. Under high salinity concentration, the estimated reduction percentages of N, P, K^+, Ca^{2+}, and Mg^{2+} contents were 22.81 and 28.99, 37.93 and 37.29, 34.97 and 37.91, 18.71 and 18.49, and 21.31 and 25.39% as compared to the control treatment for the first and second season, respectively (Table 6). But, the estimated percentage increment of Na^+ and Cl^- content under high NaCl concentration was 294.64 and 312.73 and 260.92 and 314.87% as compared to the control treatment for the first and second season, respectively.

The negative effect of salt stress on mineral elements uptake could be attributed to the low osmotic potential of the soil solution due to the increased concentration of NaCl (Khaled and Fawy, 2011). Salinity reduced N, P, K^+, Ca and Mg accumulation in plants (Navarro *et al.*, 2001) due to the competitive process by Na (Lopez and Satti, 1996). Ionic imbalance occurs in the cells due to over-accumulation of Na and Cl and

Table 6. The main effect of different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on minerals content of coriander dry leaves during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Saline water	N%		P%		K%		Na%		Cl%		Mg %		Ca %	
	1st	2nd	1st	1st	2nd	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Salt stress														
0 mM	3.42 A	3.38 A	0.58 A	0.59 A	3.06 A	3.06 A	0.56 D	0.55 D	0.87 D	0.74 D	0.61 A	0.63 A	1.71 A	1.73 A
25 mM	3.26 B	3.22 B	0.46 B	0.46 B	2.51 B	2.53 B	1.24 C	1.22 C	1.76 C	1.66 C	0.56 B	0.57 B	1.57 B	1.60 B
50 mM	2.93 C	2.89 C	0.41 C	0.43 C	2.28 C	2.19 C	1.90 B	1.97 B	2.68 B	2.57 B	0.52 C	0.52 C	1.49 C	1.53 C
75 mM	2.64 D	2.40 D	0.36 D	0.37 D	1.99 D	1.90 D	2.21 A	2.27 A	3.14 A	3.07 A	0.48 D	0.47 D	1.39 D	1.41 D
Selenium, nano-selenium, and glycine betaine														
Control	2.85 D	2.72 E	0.39 F	0.41 D	2.17 D	2.16 D	1.66 A	1.70 A	2.33 A	2.29 A	0.49 D	0.47 C	1.45 D	1.46 C
Se 1	3.18 AB	3.02 C	0.46 CD	0.48 B	2.50 B	2.49 B	1.46 B	1.48 B	2.10 B	1.98 BC	0.54 C	0.56 B	1.54 B	1.58 B
Se 2	3.10 C	3.13 B	0.45 D	0.50 A	2.51 AB	2.54 AB	1.43 B	1.48 B	2.09 B	1.91 D	0.55 AB	0.58 A	1.52 C	1.598 A
Nano-Se 1	3.11 C	2.80 D	0.49 B	0.44 C	2.51 AB	2.31 C	1.42 B	1.49 B	2.09 B	1.91 D	0.54 BC	0.56 AB	1.54 B	1.59 AB
Nano-Se 2	2.82 D	2.76 DE	0.41 E	0.43 C	2.41 C	2.31 C	1.43 B	1.42 C	2.10 B	1.93 CD	0.55 BC	0.55 B	1.57 A	1.58 AB
GB 1	3.15 BC	3.15 B	0.47 C	0.47 B	2.55 AB	2.55 A	1.48 B	1.48 B	2.04 B	2.04 B	0.56 A	0.56 AB	1.58 A	1.58 AB
GB 2	3.23 A	3.23 A	0.51 A	0.51 A	2.57 A	2.57 A	1.46 B	1.46 BC	2.03 B	2.03 B	0.56 A	0.56 B	1.58 A	1.58 B

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test (*P* ≤ 0.05); n = 3; Means with the same capital letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

reduced uptake of other mineral nutrients, such as nitrogen leading to the suppression in growth (Karimi *et al*., 2005). The present results were in parallel with those reported by Elhindi *et al*. (2016) on coriander.

Regarding the main effect of different rates of selenium, nano-selenium, and glycine betaine on coriander leaves minerals content, data in Table (6) indicated that spraying coriander plants with selenium, nano-selenium, and glycine betaine significantly increased N, P, K^+, Ca and Mg contents and decreased Na^+ and Cl^- contents of coriander plants leaves as compared to control (spraying with tap water) in both seasons. The highest mean values of N, P and K^+ contents were recorded at the application of glycine betaine at 10 mM in both seasons. Also, the highest mean values of Mg content were recorded with glycine betaine at 5 and 10 mM in both seasons and with selenium at 50 ppm in the second season. The highest mean values of Ca content was recorded with glycine betaine at 5 and 10 mM in both seasons and nano selenium at 50 ppm in the first season and 50 ppm selenium in the second season. While, the lowest contents of N, P, K^+, Ca and Mg were obtained with control. As for the sodium and chloride contents, the highest values were observed with control.

Exogenously application of glycine betaine improved the plant nutrient content of the salt-stressed coriander plants. While it decreased the concentration of Na and Cl elements under salinity conditions. The tendency for higher contents of N, P, and K in plants treated with glycine betaine under salinity conditions showed that plants could absorb more nutrients compared to untreated ones and this reflected on overall plant growth (Abdel-Mawgoud, 2017). These results were in harmony with earlier results in which glycine betaine treatments improved the uptake of nutrient elements but decreased the accumulation of Na (Habib *et al*., 2012 on okra). Foliar application of selenium led to increased absorption of N, P, K, Ca and Mg and decreased absorption of Na and Cl under salt stress conditions. Boghdady *et al*. (2017) found that foliar spraying with selenium at low concentrations had a positive effect on a significant increase of N, P and K percentage in faba bean seeds.

The effect of the interaction between the different salinity concentrations and different rates of selenium, nano-selenium, and glycine betaine on leaves minerals content of coriander plants were significant during both seasons Table (7). The statistical analysis, generally, revealed that the highest values of N, P, K, Ca and Mg and the lowest values of Na and Cl of coriander were achieved by spraying coriander plants with selenium, nano-selenium, and glycine betaine under control treatment in both seasons.

Fruit yield, fruit essential oil percentage and oil yield:

Regarding the effect of salt stress on fruit yield per plant, the results of fruit essential oil percentages and essential oil yield of coriander plants shown in Table (8). The results showed that fruit yield per plant and essential oil yield were significantly decreased with increasing level of salinity up to the highest concentration in both seasons. On the other hand, essential oil percentage increased with raising salinity levels up to the highest concentration in both seasons. The reason behind fruit yield reduction under salinity was inadequate photosynthesis owing to stomatal closure and consequently limited carbon dioxide uptake (Zhu, 2001). The obtained results on fruit yield reduction were in accordance with those reported by Ashraf and Orooj (2006) on ajwain and Neffati *et al*. (2011) on coriander.

The increment of essential oil percentage under salt stress could be due to a higher oil gland density (Charles *et al*., 1990). Also, salinity might affect the essential oil accumulation indirectly through its impact on either net assimilation or the partitioning of assimilation growth and differentiation processes (Charles *et al*., 1990). Neffati *et al*. (2011) found that the oil yield of coriander fruit based on the dry weight was increased

Table 7. The interaction effect between different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on minerals content of coriander dry leaves during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Salinity concentrations	Trts.	N%		P%		K%		Na%		Cl%		Mg%		Ca%	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
0 mM	Control	3.38 b-d	3.33 c-e	0.53 c	0.57 c-e	2.91 b	2.87 b	0.53 j	0.59 j	0.87 f	0.78 m-o	0.57 d-f	0.58 bc	1.71 a	1.72 a
	Se 1	3.57 a	3.38 bc	0.60 ab	0.61 a	3.06 a	3.15 a	0.53 j	0.45 j	0.89 f	0.68 no	0.60 bc	0.63 a	1.69 a	1.74 a
	Se 2	3.39 b-d	3.46 ab	0.58 b	0.60 ab	3.08 a	3.24 a	0.57 j	0.53 j	0.88 f	0.63 o	0.60 bc	0.64 a	1.70 a	1.75 a
	Nano-Se 1	3.50 a-c	3.31 c-e	0.62 a	0.55 de	3.08 a	2.77 bc	0.58 j	0.57 j	0.89 f	0.75 m-o	0.60 bc	0.64 a	1.70 a	1.72 a
	Nano-Se 2	3.20 e-g	3.27 d-f	0.51 c	0.58 b-d	3.06 a	3.12 a	0.55 j	0.57 j	0.88 f	0.67 o	0.61 bc	0.64 a	1.71 a	1.71 a
	GB 1	3.38 b-d	3.38 bc	0.59 ab	0.59 a-c	3.13 a	3.13 a	0.56 j	0.56 j	0.87 f	0.87 m	0.63 ab	0.63 a	1.72 a	1.72 a
	GB 2	3.51 ab	3.51 a	0.60 ab	0.60 ab	3.13 a	3.13 a	0.56 j	0.56 j	0.82 f	0.82 mn	0.65 a	0.65 a	1.72 a	1.72 a
25 mM	Control	3.12 g-i	3.10 gh	0.39 hi	0.41 k-m	2.22 h-l	2.25 hi	1.37 g	1.35 g	1.99 d	1.93 i	0.51 ij	0.49 h-j	1.47 g	1.46 g
	Se 1	3.30 d-f	3.22 ef	0.47 d	0.48 f-h	2.48 ef	2.50 ef	1.12 i	1.19 hi	1.62 e	1.49 l	0.56 d-g	0.58 bc	1.56 de	1.596 cd
	Se 2	3.32 d-f	3.26 d-f	0.44 e-g	0.50 f	2.56 de	2.58 de	1.24 g-i	1.18 hi	1.78 e	1.47 l	0.57 d-f	0.60 b	1.53 ef	1.63 bc
	Nano-Se 1	3.31 d-f	3.19 fg	0.52 c	0.42 j-m	2.64 cd	2.66 cd	1.21 hi	1.10 i	1.73 e	1.59 kl	0.57 d-f	0.57 c-e	1.57 cd	1.63 bc
	Nano-Se 2	3.09 g-i	3.09 gh	0.41 gh	0.44 i-l	2.37 fg	2.41 fg	1.24 g-i	1.17 hi	1.78 e	1.75 j	0.57 d-f	0.58 bc	1.6 bc	1.64 b
	GB 1	3.35 cd	3.35 b-d	0.45 d-f	0.45 h-j	2.59 c-e	2.59 de	1.28 gh	1.28 gh	1.70 e	1.70 jk	0.59 cd	0.59 bc	1.62 b	1.62 bc
	GB 2	3.34 de	3.34 cd	0.54 c	0.54 e	2.70 c	2.70 cd	1.25 g-i	1.25 gh	1.68 e	1.68 jk	0.57 de	0.57 cd	1.64 b	1.64 bc
50 mM	Control	2.64 o	2.69 jk	0.34 kl	0.36 pq	2.13 kl	2.06 kl	2.16 b	2.27 b	3.07 b	3.03 bc	0.46 k	0.43 l	1.38 i	1.40 h
	Se 1	3.04 h-j	3.02 h	0.43 e-g	0.44 i-k	2.28 g-j	2.22 hij	1.93 de	2.01 de	2.71 c	2.63 e	0.51 ij	0.53 fg	1.51 f	1.56 de
	Se 2	3.00 i-k	3.05 h	0.41 gh	0.49 fg	2.26 gk	2.26 hi	1.87 d-f	1.99 e	2.64 c	2.46 f-h	0.54 f-h	0.55 ef	1.47 g	1.57 de
	Nano-Se 1	2.91 j-l	2.58 l	0.45 d-f	0.41l mn	2.32 g-i	2.10 j-l	1.76 f	1.98 e	2.56 c	2.34 h	0.51 h-j	0.54 f	1.47 g	1.55 ef
	Nano-Se 2	2.67 no	2.62 kl	0.37 i-k	0.38 n-p	2.30 g-i	2.01 l	1.80 ef	1.79 f	2.63 c	2.40 gh	0.51 h-j	0.54 fg	1.55 d-f	1.54 ef
	GB 1	3.09 g-i	3.09 gh	0.43 fg	0.43 j-m	2.32 g-i	2.32 gh	1.96 cd	1.96 e	2.53 c	2.53 e-g	0.55 e-g	0.55d ef	1.54 d-f	1.54 ef
	GB 2	3.19 f-h	3.19 fg	0.46 de	0.46 g-i	2.34 gh	2.34 gh	1.80 ef	1.80 f	2.60 c	2.60 ef	0.53 g-i	0.53 fg	1.51 f	1.51 f
75 mM	Control	2.24 p	1.74 o	0.30 m	0.28 r	1.43 n	1.45 n	2.58 a	2.58 a	3.39 a	3.42 a	0.41 l	0.40 m	1.24 j	1.27 i
	Se 1	2.83 lm	2.47 m	0.34 kl	0.38 op	2.18 i-l	2.08 j-l	2.23 b	2.27 b	3.19 b	3.11 b	0.49 j	0.49 ij	1.39 i	1.41 h
	Se 2	2.68 no	2.76 ij	0.37 i-k	0.40 m-o	2.14 j-l	2.09 j-l	2.09 bc	2.22b c	3.06 b	3.06 bc	0.50 j	0.51 gh	1.38 i	1.43 gh
	Nano-Se 1	2.73 m-o	2.11 n	0.35 j-l	0.37 p	2.00 m	1.71 m	2.12 b	2.31 b	3.16 b	2.95 cd	0.49 j	0.47 jk	1.41 hi	1.45 gh
	Nano-Se 2	2.32 p	2.08 n	0.33 l	0.34 q	1.90 m	1.68 m	2.12 b	2.13 cd	3.09 b	2.88 d	0.51 ij	0.46 k	1.43 h	1.41 gh
	GB 1	2.79 l-n	2.79 ij	0.38 h-j	0.38 op	2.18 i-l	2.18 i-k	2.13 b	2.13 cd	3.05 b	3.05 bc	0.49 j	0.49 h-j	1.43 h	1.43 gh
	GB 2	2.86 k-m	2.86 i	0.42 fg	0.42 j-m	2.12 l	2.12 j-l	2.21 b	2.21 bc	3.03 b	3.03 bc	0.50 ij	0.50 hi	1.43 h	1.43 gh

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test ($P \leq 0.05$); n = 3; Means with the same small letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

Table 8. The main effect of different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on the fruit yield per plant, fruit essential oil percentage and essential oil yield of coriander during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Saline water	Fruit yield per plant (g/plant)		Fruit essential oil (%)		Essential oil yield (µl/g)	
	1nd	2nd	1nd	2nd	1nd	2nd
Salt stress						
0 mM	2.51 A	2.47 A	1.07 C	1.10 C	26.70 A	27.07 A
25 mM	2.32 B	2.30 B	1.14 B	1.15 B	26.34 A	26.51 B
50 mM	1.73 C	1.67 C	1.16 A	1.17 B	20.16 B	19.54 C
75 mM	1.12 D	1.11 D	1.19 A	1.19 A	13.23 C	13.17 D
Selenium, nano-selenium, and glycine betaine						
Control	1.57 D	1.56 D	1.11 C	1.14 C	17.31 D	17.65 D
Se 1	2.05 B	1.99 B	1.14 A-C	1.16 A-C	23.25 B	22.93 B
Se 2	2.00 B	1.98 B	1.16 AB	1.17 AB	22.63 B	22.48 B
Nano-Se 1	1.80 C	1.76 C	1.14 BC	1.15 BC	20.59 C	20.45 C
Nano-Se 2	1.74 C	1.72 C	1.12 BC	1.14C	20.25 C	20.08 C
GB 1	2.07 B	2.03 B	1.14 BC	1.15 A-C	22.74 B	22.90 B
GB 2	2.20 A	2.17 A	1.17 A	1.17 A	24.48 A	24.54 A

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test (*P* ≤ 0.05); n = 3; Means with the same capital letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

by 77 and 84% at 50 and 75 mM NaCl, respectively compared with control. The aforementioned results of increasing fruit essential oil percentage under salt stress were in agreement with Ben Taarit *et al*. (2009) on sage and Karray-Bouraoui *et al*. (2009) on *Mentha pulegium*. On the other hand, the reduction in essential oil yield per plant under salt stress may be attributed to the reduction in leaf area and photosynthesis which lead to the reduction of the number of fruits per umbrella then decreasing fruit yield per plant.

In relation to the effect of different selenium rates, nano-selenium, and glycine betaine on fruit yield per plant, fruit essential oil percentage and essential oil yield per plant of coriander plants, the data in Table (8) indicated that spraying the coriander plants with selenium, nano-selenium, and glycine betaine significantly increased fruit yield per plant, fruit essential oil percentage and essential oil yield as compared to control treatment and the highest mean values were observed at 10 mM glycine betaine.

This improvement in fruit yield per plant, fruit essential oil percentage and essential oil yield of coriander plants due to glycine betaine application would be resulted from the beneficial effect of glycine betaine on growth and metabolism and its role as an osmoprotectant. These results were relatively similar to that reported by Sadaghiani *et al*. (2019) on chamomile. Also, selenium treatment resulted in an increase in fruit yield and that might be due to its role in increasing photosynthesis rate which causes more seed growth and conservation. Boldrin *et al*. (2013) found that foliar application with selenium increased grain yield of rice plants.

The effect of interaction between the different salinity concentrations and different rates of selenium, nano-selenium, and glycine betaine on fruit yield per plant, fruit essential oil percentage and essential oil yield of coriander plants were significant during both seasons (Table 9). The statistical analysis, generally, revealed that the highest value of fruit yield per plant was observed for the control combined with 10 mM

Table 9. The interaction effect between different salinity concentrations and different levels of selenium (Se), nano-selenium (Nano-Se), and glycine betaine (GB) on the fruit yield per plant, fruit essential oil (%) and essential oil yield of coriander plants during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Salinity concentrations	Trts.	Fruit yield per plant (g/plant)		Fruit essential oil (%)		Essential oil yield (µl/g)	
		1st	2nd	1st	2nd	1st	2nd
0 mM	Control	2.38 de	2.43 c-f	1.02 g	1.09 h-j	24.57 de	26.63 a-c
	Se 1	2.52 cd	2.50 a-d	1.09 e-g	1.12 f-i	27.36 a-c	27.99 a-c
	Se 2	2.68 ab	2.70 a	1.05 fg	1.13 d-h	29.25 a	29.11 a
	Nano-Se 1	2.29 ef	2.30 d-g	1.09 e-g	1.08 ij	24.14 ef	25.44 c-e
	Nano-Se 2	2.20 f	2.13 g-i	1.05 fg	1.0633 j	25.00 c-e	24.06 d-f
	GB 1	2.65 bc	2.57 a-c	1.03 g	1.0933 h-j	27.12 a-c	27.96 a-c
	GB 2	2.82 a	2.67 ab	1.14 c-e	1.1067 g-j	29.45 a	28.32 ab
25 mM	Control	1.92 gh	1.97 ij	1.12 d-f	1.1467 c-g	21.44 g-i	22.22 fg
	Se 1	2.42 de	2.37 c-f	1.14 c-e	1.1533 c-g	27.66 b	27.32 a-c
	Se 2	2.43 de	2.43 c-f	1.17 a-d	1.18 a-e	27.74 ab	28.05 a-c
	Nano-Se 1	2.33 ef	2.27 e-g	1.14 c-e	1.1533 c-g	27.29 a-c	26.65 a-c
	Nano-Se 2	2.22 f	2.23 f-h	1.12 d-f	1.1467 c-g	25.74 b-e	26.32 b-d
	GB 1	2.38 de	2.33 d-g	1.12 d-f	1.1267 e-h	26.62 b-d	26.76 a-c
	GB 2	2.50 cd	2.47 b-e	1.16 a-e	1.18 a-e	27.93 ab	28.28 ab
50 mM	Control	1.28 m	1.19 op	1.15 b-e	1.1433 c-g	14.80 lm	14.00 kl
	Se 1	1.92 gh	1.79 jk	1.16 a-e	1.17 a-f	22.08 f-h	20.85 gh
	Se 2	1.78 hi	1.73 kl	1.18 a-d	1.1767 a-e	20.68 h-j	20.22 g-i
	Nano-Se 1	1.65 ij	1.55 l-n	1.15 b-e	1.17 a-f	19.51 ij	18.49 hi
	Nano-Se 2	1.55 jk	1.58 lm	1.16 a-e	1.1533 c-g	18.39 jk	18.64 hi
	GB 1	1.90 gh	1.84 jk	1.16 a-e	1.18 a-e	21.91 f-i	21.00 gh
	GB 2	2.05 g	2.04 hi	1.19 a-d	1.1933 a-c	23.71 e-g	23.57 ef
75 mM	Control	0.68 o	0.64 r	1.14 c-e	1.1600 b-f	8.43 o	7.75 n
	Se 1	1.37 lm	1.32 o	1.19 a-d	1.1800 a-d	15.90 l	15.54 k
	Se 2	1.08 n	1.05 pq	1.22 ab	1.1900 a-c	12.85 mn	12.53 lm
	Nano-Se 1	0.93 n	0.92 q	1.16 a-e	1.1933 a-c	11.42 n	11.21 m
	Nano-Se 2	0.98 n	0.95 q	1.17 a-d	1.1867 a-c	11.87 n	11.30 m
	GB 1	1.34 lm	1.37 no	1.23 a	1.2100 ab	15.32 l	15.89 jk
	GB 2	1.43 kl	1.52 mn	1.21 a-c	1.2133 a	16.82 kl	18.00 ij

1st and 2nd; first season and second season. Means were compared using Tukey's Honest Significant Difference test (*P* ≤ 0.05); n = 3; Means with the same capital letters are no significantly different between different salinity concentrations or between different levels of selenium, nano-selenium, and glycine betaine.

glycine betaine in the first season and 50 ppm selenium in the second season. Also, the highest value of essential oil yield was observed for the control combined with 10 mM glycine betaine in the first season and 50 ppm selenium in the two seasons. The highest value of fruit essential oil percentage had been obtained as a result of the interaction between 75 mM NaCl treatment and foliar application with 5 mM glycine betaine in the first season and 10 mM glycine betaine in the second one.

Fruit essential oil composition:

The essential oil of coriander fruits extracted from control treatment (0 mM NaCl) and control treatment sprayed with 10 mM glycine betaine and 50 ppm selenium in both seasons were identified and illustrated in Table (10).

Data showed that the major component of the essential oil was linalool (40.81-49.74%) based on the treatment. The other constituents were geranyl acetate (5.62-7.87%), camphor (5.19-8.25%), δ-terpinene (5.08-7.50%) and α-pinene (3.98-5.31%) in both seasons. Our results were in accordance with those postulated by Bhuiyan *et al*. (2009) who found that coriander essential oil contained 53 main compounds, and the most important of these compounds were

Table 10. Essential oil composition of *C. sativum* fruits extracted from control treatment (0 mM NaCl) and control treatment treated with 10 mM glycine betaine (GB) and 50 ppm selenium (Se) during the two seasons of 2017/2018 (1st) and 2018/2019 (2nd).

Essential oil composition	Percentage of peaks of individual components relative to all peaks in the chromatogram					
	Season 1			Season 2		
	Control	Se (50 ppm)	GB (10 ppm)	Control	Se (50 ppm)	GB (10 ppm)
Linalool	40.81 C	47.68 B	49.74 A	43.54 C	45.32 B	47.47 A
Geranyl acetate	6.76 B	7.87 A	7.85 A	5.62 B	7.32 A	7.12 A
Camphor	6.51 C	7.23 B	8.16 A	5.19 C	8.25 A	7.95 B
δ-Terpinene	5.08 B	7.49 A	7.5 A	5.43 B	6.84 A	6.93 A
α-Pinene	3.98 C	4.48 B	5.03A	4.3 B	4.48 B	5.31 A
Geraniol	3.32 B	4.83 A	3.63 B	3.23 C	5.33 A	4.48 B
D-Limonene	2.13 B	2.03 B	2.54 A	2.00 B	2.84 A	2.6 A
α-Terpinolene	0.72 B	0.96 A	0.77 B	0.71 B	0.73 B	0.86 A
Camphene	0.66 C	1.12 A	0.86 B	0.53 B	0.69B	0.91 A
α-Terpineol	0.62 B	0.65 B	0.75 A	0.63 B	0.66 B	0.74 A
Borneol	0.52 B	0.75 A	0.72 A	0.54 C	0.85 A	0.71 B
Decanal	0.52 B	0.66 A	0.68 A	0.52 B	0.63 A	0.61 A
β-Myrcene	0.48 B	0.53 B	0.59 A	0.44 C	0.52 B	0.67 A
β-Citronellol	0.43 B	0.47 B	0.55 A	0.47 B	0.55 A	0.52 A
Sabinene	0.27 B	0.31 A	0.34 A	0. 20 B	0.27 A	0.25 A
2-Pentadecanone, 6,10,14-trimethyl	0.15 B	0.19 A	0.18 A	0.12 B	0.21 A	0.22 A
Hexadecanoic acid	0.13 B	0.13 B	0.15 A	0.12 B	0.15 A	0.14 A
Dodecanal	0.12 B	0.16 A	0.16 A	0.10 B	0.17 A	0.16 A
Tetradecanoic acid	0.05 A	0.06 A	0.06 A	0.03 B	0.05 A	0.04 AB
γ-Terpinene	0.04 B	0.11 A	0.05 B	0.02 B	0.04 B	0.09 A

1st and 2nd; first season and second season. Means having the same letter (s) within the same row are not significantly different according to LSD for all-pairwise comparisons test at 5% level of probability.

according to their levels of existence are linalool (37.7%) and geranyl acetate (17.6%). The chemical composition of the oil varies according to the different treatments with foliar application of selenium and glycine betaine. Foliar application of 10 mM glycine betaine was the most effective treatment compared to the other treatments on increasing α-pinene (5.03 and 5.31%) and linalool (49.74 and 49.47%) for the first and second season, respectively. Also, selenium and glycine betaine treatments were more effective treatments as compared to the control on increasing δ-terpinene and geranyl acetate contents (7.49 and 7.50 and 6.84 and 6.93%) and (7.87 and 7.85 and 7.32 and 7.12%) for the first and second season, respectively. The highest values of camphor were recorded at 10 mM glycine betaine (8.16%) in the first season and 50 ppm selenium (8.25%) in the second season.

For the rest of the essential oil composition data showed that there were no significant differences between glycine betaine and selenium on increasing sabinene, decanal, dodecanal and 2-pentadecanone, 6,10,14-trimethyl in both seasons. High values of camphene, γ-terpinene, and α-terpinolene were recorded at 50 ppm selenium in the first season and 10 mM glycine betaine in the second season. Also, high values of β-myrcene, D-limonene and α-terpineol were recorded at 10 mM glycine betaine in both seasons and 50 ppm selenium for D-limonene in the second season. Moreover, high values of β-citronellol and hexadecanoic acid were recorded at 10 mM glycine betaine in both seasons and 50 ppm selenium in the second season. Also, high values of borneol L and geraniol were recorded at 50 ppm selenium in both seasons and 10 mM glycine betaine in the first one for borneol L. Furthermore, there was no significant difference between control, selenium and glycine betaine in increasing tetradecanoic acid in the first season, but application of selenium at50 ppm resulted in the highest value in the second season. Generally, the application of growth regulators such as selenium and glycine betaine induce the synthesis of biologically active compounds and improves the pharmaceutical potential of the plant.

CONCLUSION

The results cleared that coriander vegetative growth, fruit yield, chlorophyll index, nitrogen, phosphorus, potassium content in leaves, essential oil percentages and its major components were significantly affected by salt stress. Exogenous applications of selenium and glycine betaine could improve the tolerance of coriander to salt stress. Applications of selenium and glycine betaine treatments increased fresh matter in coriander plants grown at salt-stress conditions compared to nano selenium and control treatment by altering the contents of proline, ascorbic acid, and photosynthesis rate. Also, the exogenous application of selenium and glycine betaine enhanced the major constituents of coriander essential oil; linalool, geranyl acetate, camphor, δ-terpinene, and α-pinene. Therefore, farmers might enhance the growth, yield and essential oil composition of coriander plants after applications of selenium and exogenous glycine betaine under salinity stress.

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تحسين صفات النمو ومحصول الزيت الطيار و مكوناته والتركيب الكيميائي فى نباتات الكزبرة النامية تحت ظروف الإجهاد الملحي متأثره بالسلينيوم والنانوسلينيوم والجلايسين بيتائين

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تم إجراء تجربتى أصص داخل إحدى الصوب خلال الموسمين الشتويين المتعاقبين ٢٠١٨/٢٠١٧، ٢٠١٩/٢٠١٨ وذلك لمحاولة تحسين أداء نباتات الكزبره تحت ظروف الإجهاد الملحى (٠ ، ٢٥، ٥٠، ٧٥ ملي مول / لتر من كلوريد الصوديوم) مع إمكانية تحسين نمو النباتات، التركيب الكيميائي، ونسبة ومكونات الزيت الطيار في كل موسم، حيث تم إجراء التجربة بإستخدام تصميم القطاعات الفرعية داخل نظام القطاعات كامله العشوائية. تم تكرار القطاعات ثلاث مرات وتمت إجراء التجربة في مزرعة كلية الزراعة، جامعة دمنهور، محافظة البحيرة، جمهورية مصر العربية. تم رش نباتات الكزبره بواسطه كل من السيلينيوم بتركيز (٢٥، ٥٠ جزء في المليون) و النانوسيلينيوم بتركيز (٢٥، ٥٠ جزء في المليون) والجلايسين بيتائين بتركيز (٥، ١٠ ملي مول) والماء المقطر (الكونترول). وقد تم دراسه تأثير تلك المواد على المجموع الخضرى والجذرى والمحتوى الكيميائى وكذلك نسبة ومكونات الزيت الطيار لنباتات الكزبره الناميه تحت تأثير تركيزات مختلفه من الملوحه. وقد أظهرت النتائج أن إجهاد الملوحة قد سبب ضررا معنويا للنمو الخضرى ومحصول الثمار ونسبة

ومكونات الزيت الطيار وكذلك محتوى الاوراق من المركبات الكيماويه، فى حين أنه أدي لزيادة التسرب الإليكتروليتى و كذلك محتوى الأوراق من البرولين والصوديوم والكلور. بصورة عامه فإن المواد المستخدمه من السلينيوم والنانوسلينيوم والجلايسين بيتائين أوضحت تأثيرات إيجابية مختلفه على الصفات موضع الدراسه، حيث أدت المعامله بواسطه السيلينيوم والجلايسين بيتائين الي تحسين معنوي في أداء نباتات الكزبرة تحت ظروف الإجهاد الملحي وقد إنعكس ذلك بشكل معنوي في زيادة جميع الصفات المدروسة مقارنة بالكونترول.