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Original Article

# Foliar application of potassium nitrate affects the growth and photosynthesis in coriander (*Coriander sativum L.*) plants under salinity

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**Summary.** This investigation was carried out to study the effect of foliar application of K as potassium nitrate ($KNO_3$) ability to mitigate the negative impacts of salinity on coriander (*Coriander sativum* L.) plants. In a greenhouse condition we used three levels of NaCl (0, 40 and 80 mM) applied to the growth medium and three levels of K as $KNO_3$ (0, 50 and 100 mM) adjusted two times as a foliar spray on the plants. Salt stress affected adversely the growth rate, relative content of leaf water, the plant contents of protein and chlorophyll, attributes of gas exchange containing net $CO_2$ assimilation rate, transpiration rate, stomatal conductance and substomatal $CO_2$ concentration, essential oil content and leaf $K^+$, $Mg^{2+}$, P, $Ca^{2+}$, N as well as $Na^+/K^+$ ratio, while it enhanced the electrolyte leakage, the plant contents of proline and $Na^+$. It can be concluded that the tested parameters were generally positively affected by the foliar application of the $KNO_3$ under saline and control conditions. Supplied with $KNO_3$ treatment significantly showed better tolerance towards salinity. This can be explained by the positive effects of all external $KNO_3$ application on the membrane permeability, photosynthetic activities, relative water content and nutrients balance and concentration under salinity stress conditions.

**Key words:** amelioration, exogenous application, salt tolerance, mineral content, gas exchange, potassium nitrate

## Introduction

Coriander (*Coriandrum sativum* L.) is one of the most important annual herbs in the Apiaceae family. It is originated from the Mediterranean regions it is planted for its green foliage, fruits and the production of essential oils in many parts of the world. Coriander has many medicinal benefits, as its green leaves are widely used for many medical purposes. The dried fruits have many economic important uses, it's used in many industries such as food, cosmetics, perfume and drugs industries (1). Its content of essential oil is from 0.03 to 2.6% (2).

Salinity is one of the major factors negatively affecting agriculture development in arid and semi-arid regions. Osmotic changes may induced by salt accumulation in soils, interfering with the process of nutrient uptake, enzymes inactivation and osmotic adjustment is disturbed at the cytosol and vacuoles level (3, 4). Bad agriculture practices increase senility levels in the soil and in the groundwater by the time to levels that negatively affects the plants growth and productivity (even toler-

ant crops), so to ensure agricultural sustainability and continued food production, the humanity must search for solutions for senility problems (5). Environmental stresses, such as salinity (6-8) and water stress (9), can reduce the economic value of the aromatic plants, as these stresses cause a significant reduction in secondary metabolites (the building blocks of essential oil) of these plants. Salinity, whatever its source (soil or water) significantly lower plant growth, so plants developed ways to cope by either avoiding or tolerating salt stress before growth is impaired (10). Plant growth is limited by salt salinity because of the negative salinity related effects on physiological and biochemical processes including photosynthesis, antioxidant capacity, and ion homeostasis (11). Ionic imbalance occurs in the cells due to excessive accumulation of $Na^+$ and $Cl^-$ and reduces the uptake of other essential minerals, such as K (12, 13).

Potassium plays many important roles affecting many physiological processes related to stomatal behavior, osmoregulation, enzyme activity, cell expansion, neutralization of nondiffusible negatively charged ions and membrane polarization (14, 15). $Na^+$ and $K^+$ are similar in their charge that why $Na^+$ is able to compete with $K^+$ (16), hence, higher levels of $Na^+$ (in leaf apoplast, and/or vacuole, plant) negatively affects any physiological process related to $K^+$ (17, 18). Despite the fact that foliar applied nutrients (such as K) have been reported to improve plants growth and productivity (20), there is limited amount of information related to the mechanisms of leaves nutrient uptake and the effects of leaves absorbed nutrients on different physiological processes (19). In order for plants to be able to produce 1 kg of dry weight it needs from 20 to 50 g of potassium (21). Because of salinity conditions the plants content of $Na^+$ increases and is content of $K^+$ decreases this may be explained by the Na Cl induced membrane depolarization, which causes $K^+$ leakage from the cell, and as a final result lower the $K^+/Na^+$ ratio (24). Maintaining a higher $K^+/Na^+$ ratio is of extreme importance for the plants to be able to fully control its osmotic stat, turgor maintenance, stomatal role, stimulation of enzymes, protein synthesis, photosynthesis and oxidants metabolism (22, 23). So fertilizing plants with $K^+$ in order to raise $K^+/Na^+$ ratio would be very reasonable way for the sake of increasing plants tolerance towards salinity, especially if this fertilizing process have been mad via away that lower the competence between $K^+/Na^+$ in the soil (foliar spray of K).

Putting in mind what has been mention till now, we have set the aim of this research to study the extent to which $KNO_3$ (via foliar application) can alleviate the negative effects of salt stress on coriander plant, this have been studied throw measuring various growth rate and physiological characteres (such as dry mass, production, compositions of protein and chlorophyll, gas exchange aspects, relative water content, membrane permeability and proline composition) of coriander plants treated with foliar application treated with $KNO_3$ and salinity.

## Materials and Methods

*Plant material, growth conditions and treatments*

The experiment was implemented in Dirab experimental station`s farm belonging to the college of food and agricultural sciences, King Saud university, it was implemented in the period of spring 2013. The temperature was set to 27/20°C day and night respectively, the average of relative humidity was about 70-80%, and the light intensity was set to 225 μmol $m^{-2}$ $s^{-1}$ with light period of 16 hours daily. Ten coriander (*Coriandrum sativum* L.) seeds (sterilized with 5% sodium hypochlorite solution for 10 min before plantation) were planted in each plastic pot (28 cm diameter). After the planting the seedlings number was lowered to three homogeneous seedlings for each pot. The planting media was washed sand (12.5 kg per each pot). The pots were arranged according to the completely randomized design, with three replicates. The pots surface was covered after germination with black plastic sheets to reduce soil evaporation. In the first 18 days of the experiment (after germination) the pots were irrigated using Hogland nutrients solution (full strength) (25), after those 18 day the salinity (NaCl) treatment begun. The Salinity NaCl treatment was conducted as control 0 mM (0.001 dS $m^{-1}$), 40 mM (5.0 dS $m^{-1}$) and 80 mM (8.0 dS $m^{-1}$) in full strength Hoagland's nutrient solution. The salinity treatment (in the form of Hogland solution mixed with NaCl as previously mentioned), was performed daily by Salt solution was used in aliquots of 50 mM daily, AS the weekly amount of the

treatment solution was maintained to be two liters per each pot (the moisture content was maintained in each by adding 200 ml of distilled water for each pot). The treatment of $KNO_3$ was prepared by putting the desired levels (0, 50 and 100 mM) of $KNO_3$ in the tween-20 solution (0.1%), The foliar spray of these solutions was performed with the rate of 20 ml for each pot two times during the experiment on both salinity stressed and non-stressed plants. The foliar $KNO_3$ application was conducted after the salinity treatment with one week for the first time and two weeks for the second time of application (with a control treatment left untreated with additional $KNO_3$). All the solutions of treatments whether salinity or $KNO_3$ was prepared in the 0.1% Tween-20 solution with its PH maintained on 6.5, this was made to provide the best possible penetration of the solutions to the leaves tissues and to inhibit injuries.

*The following parameters was measured Twenty two days after the salt treatment:*

*Electrolyte leakage*

In order to have a sign on the stability and the content of the cells and whiter the cells membranes was stable or not, the electrolyte leakage was measured. Electrolyte leakage was measured according to the method explained by (26).

*Proline determination*

The method used in determining the proline content is that described by (27).

*Determination of protein contents*

Protein levels were estimated by (28) using bovine serum albumin as standard and expressed as mg protein $g^{-1}$ FW.

*Essential oil content*

Before flowering and 180 days from transplanting, chemical compositions were determined. The essential oils (three plants per replicate) of the fresh herb were achieve by hydrodistillation in a Clevenger-type apparatus according to Guenther (29) for 3 hours. Essential oil was expressed as (%).

*Chlorophyll determination*

The chlorophyll content results were described as mg per gram-fresh mass (mg $kg^{-1}$ FW). The chlorophyll content was determined according to (30).

*Leaf relative water content*

Leaf relative water content (LRWC) was calculated according to method by (31). Values of FW, TW, and DW were used to calculate LRWC using the equation below:

$$LRWC\ (\%) = [(FW - DW)/(TW - DW)] \times 100$$

*Ion concentration determination*

Plant samples were dried in an oven with drift fan at 70°C until constant dry weight was obtained. N, P, $K^+$, $Ca^{2+}$, $Mg^{2+}$ and $Na^+$ were determined with a flame photometer (Jenway, PFP-7). Magnesium ($Mg^{2+}$) was estimated with anatomic absorption spectrophotometer (Perkin Elmer Analyst 300, USA). Nitrogen was determined by the micro-Kjeldhal's method (32). Phosphorus (P) was measured spectrophotometrically (33). $Cl^-$ content was estimated with a chloride analyzer (Model 926, Sherwood Scientific Ltd., Cambridge, UK).

*Gas exchange measurements*

Three plants were randomly selected from each treatment for leaf gas exchange measurements. The most recently fully expanded leaf (5th) was employed for measurements with an open gas exchange system (Li-6400, Li-Cor, Inc., Lincoln, NE, USA). Net $CO_2$ assimilation rate ($A$), transpiration rate ($E$), stomatal conductance ($g_s$), intercellular $CO_2$ concentration ($Ci$) were estimated between 9:00 and 17:00 at a photosynthetic photon flux density of 800 μmol $m^{-2}$ $s^{-1}$. In the greenhouse climate conditions in the leaf chamber were set close to conditions, like relative humidity at 75%, $CO_2$ concentration at 400 μmol $mol^{-2}$ and leaf temperature at 28±0.5°C.

*Characteristics measuring*

Data for growth parameters, yield and chemical composition for the all treatments were achieved through at the flowering stage (135 days after sowing), plant height (cm), branches number and umbels/plant as well as fresh and dry weights of herb (g/plant). Representative fresh samples from each treatment were taken for determination of essential oil content. Leaf area was estimated with the apparatus AM-Licor 1300 (Lincoln, Nebraska, USA).

*Statistical analysis*

Analysis of variance of all parameters was calculated using the COSTAT computer package (CoHort Software Inc., Berkeley, USA). The least significance difference among the mean values was computed by (34). The Duncan's New Multiple Range test (DMRT) at 5% level of probability was also used to test the difference between mean values.

## Results

*Plant growth*

There was a significant negative relationship between the salinity level and the Plant height, branches number and leaves/plant as well as fresh and dry weight of coriander plants. Those negatively affected parameters under salinity, were significantly increased under Foliar $KNO_3$ applications under both absence and presence salt stress (Tab. 1). Leaf area was also greatly reduced under salinity treatments, and was significantly increased under the application of $KNO_3$ non-saline conditions, and greatly enhanced under saline conditions with the application of $KNO_3$ (Tab. 1), in the same table the data about the umbels numbers per plant are shown, as it reveals a negative effect of salinity on the umbels number, and a substantially positive effect of $KNO_3$ application on it

*Electrolyte leakage*

AS expected the salinity treatments of 40 and 80 mM NaCl into nutrient solution had significantly increased the electrolyte leakage. The foliar sprays of $KNO_3$ was able to the electrolyte leakage values to values comparable with unstressed plants. Under non saline stress conditions, the foliar application of $KNO_3$ slightly decreased electrolyte leakage compared to control (Tab. 2).

*Osmotic regulators accumulation*

Proline was highly increased in salinity treatments, these higher rates was markedly lowered under the $KNO_3$ treated plants (Tab. 2).The leaves Protein content was significantly decreased under salinity, and a bit enhanced under foliar $KNO_3$ treatments (Tab. 2).

**Table 1**. Effect of foliar spray of $KNO_3$ on growth parameters of coriander grown under salt stressed and nonstressed plants. Values sharing same letter in a season did not differ significantly (P>0.05) (Duncan's multiple range tests). (n=3; means ± SE).

| NaCl (mM) | $KNO_3$ (mM) | Plant height (cm) | Shoot fresh weight (g) | Shoot dry weight (g) | Branch number/plant | Leaf number/ plant | Leaf area/plant ($cm^2$) | Umbels number/plant |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 64.37 ± 0.80c | 68.48 ± 0.99c | 13.19 ± 0.53c | 8.19 ± 0.10de | 228.32 ±1.10d | 136.59 ±1.35c | 17.33 ± 0.28c |
| | 50 | 72.03 ± 0.52b | 87.46 ± 0.61b | 16.59 ±0.21b | 10.07± 0.24b | 236.67± 1.01b | 147.34 ± 0.39b | 18.52 ± 0.40b |
| | 100 | 76.57 ± 0.55a | 95.05 ± 0.74a | 18.82± 0.41a | 11.62± 0.46a | 245.64± 0.64a | 153.65 ± 0.72a | 19.89 ±0.31a |
| 40 | 0 | 56.26 ± 0.80e | 53.27± 0.85h | 8.39± 0.36f | 7.64 ± 0.10f | 211.87 ± 0.71f | 122.06 ±0.50f | 11.64 ± 0.32f |
| | 50 | 60.65 ± 0.93d | 60.93 ± 0.91e | 10.28 ± 0.22e | 8.51 ± 0.27d | 224.75 ± 0.23e | 127.87 ±0.51e | 13.39 ±0.19e |
| | 100 | 63.74 ± 1.20c | 65.06 ± 0.17d | 11.44 ± 0.35d | 9.43 ± 0.09c | 231.23± 0.80c | 130.85 ± 0.34d | 14.42 ±0.05d |
| 80 | 0 | 49.48 ± .80g | 49.14 ± 0.85i | 6.61 ± 0.36h | 6.89 ± 0.10g | 162.53 ±0.71i | 95.18± 0.50i | 10.62 ± 0.32g |
| | 50 | 52.91 ±0.93f | 54.93± 0.91g | 7.48 ± 0.22g | 7.73± 0.27ef | 181.38 ± 0.23h | 108.18 ± 0.51h | 11.53 ±0.19f |
| | 100 | 55.41±1.20e | 57.38± 0.17f | 8.62 ±0.35f | 8.34± 0.09d | 199.18 ± 0.80g | 112.86 ±0.34g | 12.87 ± 0.05e |

*Essential Oil Content*

The essential oil production of coriander plants was significantly reduced under Salinity, and slightly increased under $KNO_3$ (Tab. 2).

*Chlorophyll contents*

Photosynthetic pigments (chlorophyll *a* and chlorophyll *b*) were enhanced due to the application of $KNO_3$, the same parameter (chlorophyll *a* and chlorophyll *b*) was significantly reduced under salinity (Tab. 2).

*Leaf relative water content*

Salt stress reduced leaf relative water content (LRWC) of plants compared with the control non-salt stress treatment, on the other face it was enhanced by foliar $KNO_3$ application (Tab. 2).

*Mineral ion concentrations*

Leaves content of sodium (Na) enhamced under salinity treatments, under the same salinity treatment there was a significant decrease in the leaves $K^+$ concentration, the $K^+/Na^+$ ratio being significantly reduced, those all negative salinity effects was alleviated in the $KNO_3$ treated plants (Tab. 3).

**Table 2**. Effect of foliar spray of $KNO_3$ on electrolyte leakage, chlorophyll, protein, proline, essential oil percentage and leaf relative water content of coriander grown under salt stressed and nonstressed plants. Values sharing same letter in a season did not differ significantly (P>0.05) (Duncan's multiple range tests). (n=3; means ± SE).

| NaCl (mM) | $KNO_3$ (mM) | Electrolyte leakage (%) | Chlorophyll a (mg/g FW) | Chlorophyll b (mg/g FW) | Protein (mg/g FW) | Proline (µM/g FW) | Essential oil content (%) | Leaf relative water content (%) |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 27.67 ± 0.12$^{f}$ | 0.30 ± 0.01$^{c}$ | 0.11 ± 0.01$^{bc}$ | 17.61 ±0.89$^{c}$ | 5.27 ± 0.04$^{f}$ | 0.58 ± 0.01$^{e}$ | 58.33 ± 0.58$^{c}$ |
| | 50 | 21.77 ± 0.80$^{g}$ | 0.34 ± 0.01$^{b}$ | 0.12± 0.01$^{b}$ | 20.40 ± 1.00$^{b}$ | 4.24 ± 0.35$^{g}$ | 0.67 ± 0.01$^{c}$ | 64.0 ± 0.58$^{b}$ |
| | 100 | 18.51 ± 0.50$^{h}$ | 0.36 ± 0.01$^{a}$ | 0.14 ± 0.01$^{a}$ | 23.37 ± 0.60$^{a}$ | 3.38 ± 0.10$^{g}$ | 0.85 ± 0.01$^{a}$ | 74.67 ±0.58$^{a}$ |
| 40 | 0 | 34.77± 0.79$^{d}$ | 0.27 ± 0.01$^{f}$ | 0.09 ± 0.01$^{d}$ | 13.52 ± 0.19$^{ef}$ | 13.73 ± 1.02$^{c}$ | 0.52 ± 0.01$^{f}$ | 48.33 ± 1.00$^{f}$ |
| | 50 | 32.50 ± 1.12$^{e}$ | 0.29 ± 0.01$^{d}$ | 0.09 ± 0.01$^{cd}$ | 14.23 ± 0.26$^{de}$ | 11.82 ± 0.39$^{d}$ | 0.62 ± 0.01$^{d}$ | 51.67 ± 0.58$^{e}$ |
| | 100 | 31.19± 0.64$^{e}$ | 0.30 ± 0.01$^{c}$ | 0.11± 0.00$^{bc}$ | 15.24 ± 0.87$^{d}$ | 10.52 ± 0.74$^{e}$ | 0.69 ± 0.01$^{b}$ | 54.66 ± 0.58$^{d}$ |
| 80 | 0 | 44.70 ± 0.79$^{a}$ | 0.24 ± 0.01$^{h}$ | 0.08 ± 0.01$^{e}$ | 11.16 ± 0.19$^{h}$ | 18.71 ± 1.02$^{a}$ | 0.47 ± 0.01$^{g}$ | 32.0 ± 1.00$^{i}$ |
| | 50 | 41.50 ±1.12$^{b}$ | 0.26 ± 0.01$^{g}$ | 0.09 ± 0.01$^{cd}$ | 12.03 ± 0.26$^{gh}$ | 16.39 ± 0.39$^{b}$ | 0.53 ± 0.01$^{f}$ | 35.33 ± 0.58$^{h}$ |
| | 100 | 38.57 ± 0.64$^{c}$ | 0.28± 0.01e | 0.1± 0.00$^{cd}$ | 12.97 ± 0.87$^{fg}$ | 14.04 ± 0.74$^{c}$ | 0.63 ± 0.01$^{d}$ | 41.67 ± 0.58$^{g}$ |

**Table 3**. Effect of foliar spray of $KNO_3$ on leaf ionic composition of coriander grown under salt stressed and nonstressed plants. Values sharing same letter in a season did not differ significantly (P>0.05) (Duncan's multiple range tests). (n=3; means ± SE).

| NaCl (mM) | $KNO_3$ (mM) | N | P | K | Ca | Mg | Na | K/Na ratio | Cl |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 3.25 ± 0.01$^{d}$ | 0.52 ±0.01$^{c}$ | 19.71 ± 0.12$^{f}$ | 1.75 ±0.16$^{c}$ | 0.54 ±0.01$^{d}$ | 6.43 ± 0.16$^{g}$ | 3.06 ± 0.07$^{c}$ | 9.47 ± 0.25$^{g}$ |
| | 50 | 3.35 ± 0.01$^{c}$ | 0.53 ± 0.01$^{b}$ | 25.95 ± 0.68$^{d}$ | 1.83 ± 0.25$^{b}$ | 0.58 ± 0.01$^{b}$ | 5.43 ± 0.25$^{h}$ | 4.78 ± 0.02$^{b}$ | 7.60 ± 0.58$^{h}$ |
| | 100 | 4.28 ± 0.01$^{a}$ | 0.62 ±0.01$^{a}$ | 38.97 ± 0.39$^{a}$ | 1.86 ±0.07$^{a}$ | 0.65 ± 0.00$^{a}$ | 4.18 ± 0.07i | 9.31 ± 0.04$^{a}$ | 6.50 ± 0.50$^{i}$ |
| 40 | 0 | 3.03 ± 0.02$^{f}$ | 0.34 ± 0.00$^{g}$ | 12.81 ± 0.20$^{h}$ | 1.32 ± 0.16$^{g}$ | 0.51 ± 0.01$^{e}$ | 32.29 ± 0.16$^{c}$ | 0.39 ± 0.00$^{gh}$ | 47.09 ± 0.51$^{d}$ |
| | 50 | 3.13 ± 0.01$^{e}$ | 0.37 ±0.01$^{e}$ | 20.99 ± 0.45$^{e}$ | 1.47 ±0.06$^{e}$ | 0.53 ± 0.01$^{d}$ | 24.33 ± 0.06$^{d}$ | 0.86 ± 0.01$^{f}$ | 32.64 ± 0.30$^{e}$ |
| | 100 | 3.82 ± 0.02$^{b}$ | 0.44± 0.01$^{d}$ | 30.81 ± 0.80$^{b}$ | 1.63 ±0.51$^{d}$ | 0.56 ±0.01$^{c}$ | 12.57 ± 0.51$^{f}$ | 1.45 ± 0.02$^{d}$ | 27.17 ± 0.40$^{f}$ |
| 80 | 0 | 2.05 ± 0.02$^{f}$ | 0.31 ±0.00$^{h}$ | 11.47 ± 0.20i | 1.27± 0.01$^{h}$ | 0.47 ± 0.01$^{f}$ | 48.47 ± 0.16$^{a}$ | 0.23 ±0.00$^{h}$ | 66.93 ± 0.51$^{a}$ |
| | 50 | 2.52 ± 0.01$^{e}$ | 0.34 ± 0.01$^{g}$ | 18.14 ± 0.45$^{g}$ | 1.31 ± 0.01$^{g}$ | 0.50± 0.01$^{e}$ | 36.56 ± 0.06$^{b}$ | 0.45 ± 0.01$^{g}$ | 60.90 ± 0.30$^{b}$ |
| | 100 | 2.82 ± 0.02$^{b}$ | 0.34 ± 0.01$^{f}$ | 28.69 ± 0.80$^{c}$ | 1.35 ±0.01$^{f}$ | 0.52± 0.01$^{d}$ | 22.71 ± 0.51$^{e}$ | 1.26± 0.02$^{e}$ | 51.86 ± 0.40$^{c}$ |

*Gas-exchange parameters*

In Figure (1) shows that all gas exchange parameters like net $CO_2$ assimilation rate (*A*), transpiration rate ($E_i$), stomatal conductance ($g_s$) and sub-stomatal $CO_2$ concentration (*C*) were significantly decreased as a result of salt stress. However, these parameters were considerably increased under the foliar application of $KNO_3$. Furthermore, stomatal conductance and sub-stomatal $CO_2$ concentration were enhanced especially in the salt-stressed coriander plants by reason of foliar applied varying levels of $KNO_3$.

## Discussion

Under salinity stress conditions, the productivity of coriander plants (green herb and fruits) and the chlorophyll concentrations are significantly reduced. One of the main effects of salinity that might explain its negative relation with plant productivity is the adverse effects of salinity on the physiological process such as photosynthesis, nutrient homeostasis and storage of compatible solutes (35). There is a significant negative relationship between salinity and plants shoot length, fresh and dry weights and leaf area (36). The adverse salinity related effects of salinity on leaf area may be explained by the reduction in the photosynthesis rate. Hence, reduction in the energy, and metabolites synthesis, and the toxic disorders effects of $Na^+$ and $Cl^-$, then lowering the cells turgor pressure and cellular expansion (21). Similarly, salinity stress negative impacts on plants shoot and root growth was observed in other plants like maize (37). The increased sodium content in plant tissues because of salinity negatively affects the nutrients balance and the osmotic status of cells (38, 39), as the accumulation of unnecessary imbalanced ions (ion toxicity) in tissues of plants is often seen as the main cause of productivity reduction under salinity (40). One of the methods that have been re-

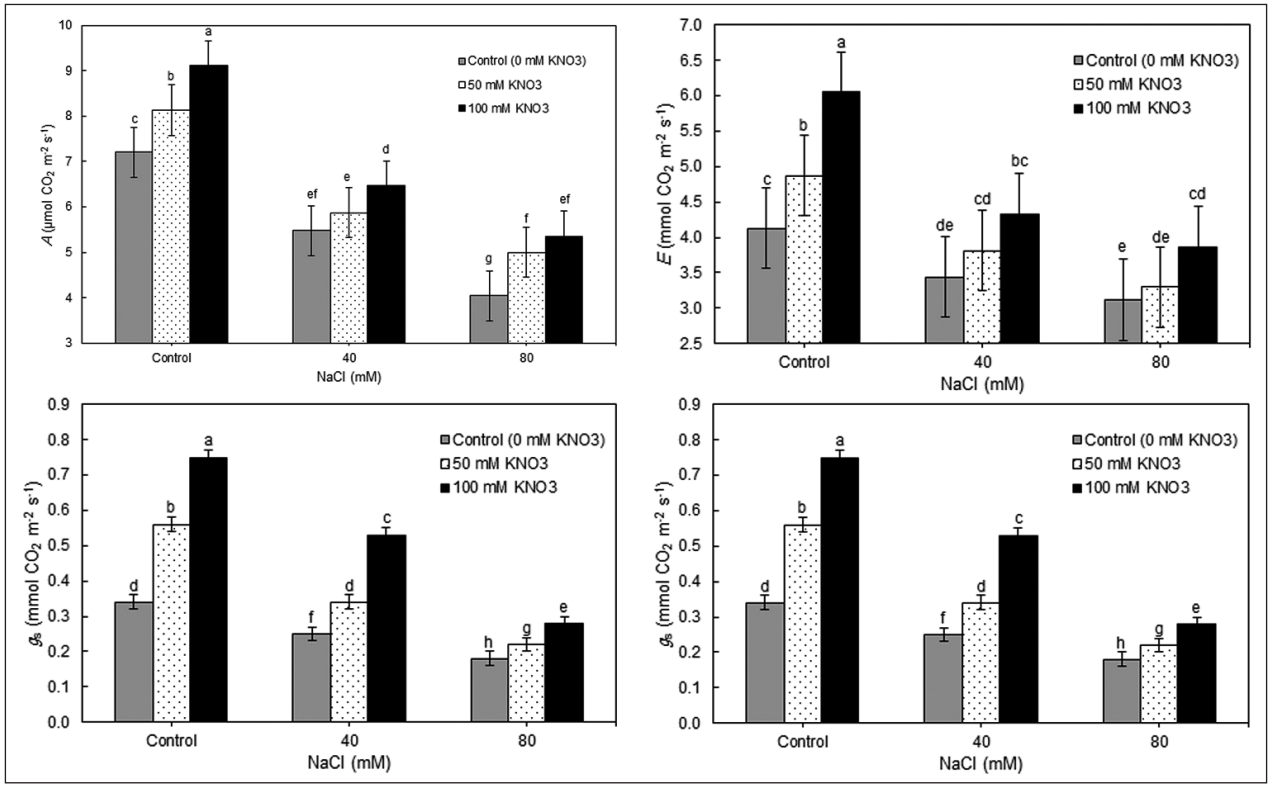


**Figure 1.** Impact of $K^+$ application (mM) as $KNO_3$ on net $CO_2$ assimilation rate ($P_N$), transpiration rate (*E*), stomatal conductance ($g_s$), intercellular $CO_2$ concentration (*Ci*) in coriander grown at 0 mM, 40 mM and 80 Mm NaCl. Values are means ± SE (n=3). The data bars having same letter in a season did not differ significantly (P>0.05), according to Duncan's Multiple Range Test.

ported to alleviate the negative effects of salinity is the foliar spray of inorganic salts (41-45). The results of this study clearly indicated that the foliar spray with $KNO_3$ was effective in mitigating the negative effects of salinity on coriander plants. The foliar application with $KNO_3$ on salinity treated plants enhancing the nutrients balance in the plants tissues, as it helped improving the K and N ratio in the tissues of salt treated plant. Hence reducing the toxic effects of salinity. The Foliar spray of $KNO_3$ had increased the plants growth through enhancing the physiological processes as K has a key role in the stomatal conductance, photosynthesis osmoregulation, protein synthesis and turgor-pressure-driven solute transport in xylem to plants (11, 21), nitrate metabolism (Nitrogen is an active participant of chlorophyll) (46). One of the major reasons of salinity (NaCl) negative effects is the competence between $Na^+$ and $K^+$ in the rhizosphere zone, which leads to the nutrient imbalance in the plant tissues, and then low production (48). This was the case in many plants as reported in rice plants grown under salinity stress (NaCl), as the $K^+$ content in those rice plants was low (47). The higher $K^+$ contents in plant tissue under salt stress could be due to ability of plant to do selective $K^+$ uptake and selective cellular $K^+$ and $Na^+$ compartmentation and their distribution in the shoots (49). For the previous mentioned reasons any addition of $K^+$ would enhance the plant productivity under salinity stress, this was the case in our experiment, as the exogenous application of $K^+$ was able to alleviate the negative effects of salinity. Our results are in corroboration with the findings of (50) for tomato, maize, sunflower and beans, (20) for sunflower and (51) for barley.

In our results the electrolyte leakage we used as a sign on the membrane permeability. The excess of NaCl in the cell has a negative effect on the membrane permeability, this is what was revealed as the increased concentration of NaCl causes the electrolyte leakage to increase (as a result of negative effects on membrane permeability). Hence, leads to an adverse effect on the physiological and biochemical processes which can cause premature leaf senescence and loss of photosynthetic efficiency that, in turn, reduces carbon fixation, and as a final result the plant growth and productivity. In the present study the foliar application with $KNO_3$ improving the cells water stays and turgor pressure by enhancing the nutrients balance, this helps the cells membranes to hold its permeability in a safe status keeping its selectivity, These results reporting the positive effects of $KNO_3$ on membranes permeability under salinity stress came in accordance with other reports (35, 52-55).

An obvious increase in Ca content in the plant leaves even under salinity stress conditions, when $KNO_3$ was applied in our study. Ca has been reported a critical role in helping plasma to maintain its membrane integrity (56), it has been also reported an essential role in preserving the structural and functional integrity of plant membranes, stabilizing cell wall structures, regulating ion transport and selectivity and controlling ion-exchange behavior as well as cell wall enzyme activities (50).

One of the main mechanisms is osmotic adjustment, which is achieved through the accumulation of organic solutes (*e.g.* proline and protein) in the cytosol and other organelles. Proline is of extreme importance for plants under stress conditions, as it helps in regulating the osmotic pressure, maintain membrane integrity, stabilization of enzymes/proteins and scavenger of free radicals (57). Under salinity stress conditions the vacuolar $Na^+$ concentrations is increased, this makes the plant needs another necessary nutrient with a similar charge to help rebalance and regulate its osmotic pressure of the cytoplasm, this can be achieved by the application of $K^+$ (58). With the supplementary $K^+$ (amounts of 50 and 100 mM) the proline content was significantly enhanced under salinity stress conditions, it is worth adding that under salinity stress conditions the proline content may raise due to the hydrolysis of proteins (59).

Under salinity conditions, proteins play a critical role as it may be accumulated to serve as a storage form of nitrogen that may be re-utilized later (62), it may also play a role in osmotic adjustment. The data shown in Table 2 clearly indicateed a significant decrease in the protein content of coriander plants under salinity stress conditions. This reduction may be explained by the negative salinity induced changes in the ratio between soluble amino acids and proteins, as salinity may increase break down of protein by proteolytic process. This came in accordance with what have been reported in chamomile and sweet marjoram plants under salin-

ity stress conditions (60) and *Achillea fragratissima,* as the salinity level of 4000 ppm depressed significantly crude protein (61). Foliar application with $KNO_3$ has caused the soluble protein concentrations to increase under both saline and non-saline conditions. The $K^+$ related effect may be due to its role in the translation process (especially in binding of tRNA to ribosomes) (63). The exogenous application of $KNO_3$ is related to improved $NO_3^-$ absorption and its reduction and assimilation (64).

The coriander oil production was decreased significantly under salinity stress conditions. Our results are support the findings of 65, 66, and 67 who reported that the essential oil yield enhanced significantly with increasing NaCl concentrations in the area of coriander roots (68, 69). These results are in confirmation with the results of (70, 71) who reported a negative relationship between the salinity level and the oil content. This negative relationship may be explained by the decreasing rate to the anabolism activities in plant cells under salinity stress conditions (72), the reduction in photosynthetic rates (7), to the faster maturity process to the fruits under salinity stress, leading to higher percentage of the fruits shell (hull) and less developed seeds with lower contents of oil (73).

Chlorophyll concentration is of extreme important to the photosynthesis process. Hence for the production of metabolites, it is considered as an indicator of cellular metabolic state. Salinity is known to disturb and negatively affect the pigment content in the plant through the reductions of chlorophyll contents (74-76). In our present experiment the chlorophyll content in salinity affected coriander plants was significantly lower when compared to the control plants However, with the $KNO_3$ treated plants having a greater chlorophyll content values than control. This may be due to the oxidation of chlorophyll and other chloroplast pigments coupled with instability of the pigment protein complex under salt stress conditions (35). The enhanced chlorophyll content in the $KNO_3$ treated plants reveal that the $K^+$ has (partially) reversed the negative effects of NaCl on chlorophyll. The better membranes status under $KNO_3$ application and due to the better antioxidant activity under $KNO_3$ foliar application (21).

Salinity stress is known to lower the leaf relative water content (LRWC) (75); this clearly indicate that under salinity stress conditions there would be a significant loss in the turgor pressure resulting in limited water availability for the cell-extension process. The plants daily water usage was greatly enhanced under the foliar $KNO_3$ treatment (enhancement to values near those in unstressed plants). This treatment helped the plant to restore its normal plant cell water relations and alleviating the effects of salinity.

In the present experiment, foliar application with $KNO_3$, has greatly increased the $K^+$ content in coriander tissues under both stressed and non-stressed conditions. Under the higher concentration of $K^+$ by foliar application, the plants leaves were injured with a subsequent reduction in accumulation of $K^+$ in the leaves. This reduction may be due to destruction of ectodesmata structures (21). This came in accordance with (77) who reported that the leaf burning under foliar spray with high concentration can be overcome by using low salt index fertilizers containing low $K^+$ and proper adjuvant. Salt-induced lower leaf $K^+$ content, this negative effect was alleviated by the leaf-applied $K^+$. These results accordance with those reported in other crops (15, 31, 78).

Under salinity stress, the data showed that the accumulation of $Na^+$ and $Cl^-$ was increased, and the accumulation of N, P, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ was decreased in coriander plants. These findings are generally in agreement with (79, 44, and 45). The foliar application of $K^+$ has greatly enhanced $K^+/Na^+$ ratio in salt stressed plants (Tab. 3).

Our results indicated that the foliar application with $KNO_3$ has significantly enhanced the treated plants net photosynthetic rate ($A$), stomatal conductance ($g_s$) and intercellular $CO_2$ concentration ($C_i$), with the most effective level observed was 100 mM $KNO_3$. This came in accordance with the finding of other plant species (80, 81). This photosynthetic enhanced rate due to the application of $KNO_3$ increases the plants dry matter productivity (82). Foliar application with $KNO_3$ under salinity treatment levels (40 and 80 mM) significantly improved stomatal conductance, net photosynthesis, leaf area and plant dry weight. Stomatal conductance, is of extreme importance in controlling photosynthetic rate and water balance of plants under stress conditions (83, 84). Fig. (1) shows that the stomatal conductance was greatly improved due to the

application of $KNO_3$, particularly of the salt-stressed plants of coriander. This $K^+$ positive effect under stress conditions may be due to its role as an osmolyte in the vacuoles (21). In view of some earlier reports, stomatal regulation largely depends upon the distribution of $K^+$ in epidermal cells, guard cells and leaf apoplast (24). The positive effects of K+ on stomatal conductance on the mobilization of internal tissue nitrate and on the chlorophyll biosynthesis may explain increase in photosynthetic rate due to foliar application of $K^+$ (83-85).

## Conclusions

The experiments clearly indicated the valuable impacts of $KNO_3$ application on growth rate, chlorophyll content, photosynthetic activity, protein and proline compositions, uptake of mineral elements or reduced Na uptake, membrane injuries of coriander plants, regardless to their growth under non saline or saline stress conditions. Therfore, the $KNO_3$ applications might help mitigate the adverse impact of salinity in coriander plants. Hence, this protective effect induce a reduce in the ratio of $Na^+/K^+$ in coriander leaves, which is a critical determinant under salt stress.

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