Effect of Silicon Application on *Coriandrum sativum* (L) Under Salt Stress

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Abstract— In the present era, because of the continuous increase of various biotic and abiotic stresses, the growth of plants may be restrained by these stresses. The addition of Silicon (Si) as a biofertilizer is known as an ecologically compatible and environmentally friendly technique to improve plant growth, alleviate various biotic and abiotic stresses in plants, and enhance the plant resistance to multiple stresses. This study inquiry about the effect of Silicon application on coriander Coriandrum sativum grown under salt stress; Therefore, an experiment was conducted with seeding in pots with 50 mM, 100 mM of NaCl and 1 mM of silicon in its soluble form monosilicic acid (H_4SiO_4). The experimental design was a randomized complete block with three repetitions. The results showed that in the salt conditions, fresh and dry biomasses were decreased mainly at 100 mM treatment, whereas, Silicon application enhanced these biomasses. Moreover, boosted RWC, K^+ contents and K^+/Na^+ ratio, chlorophyll contents, and carotenoids. However, the proline content decreased significantly with the Silicon application. In the light of the obtained results, Silicon reduced the adverse effect of salinity for coriander, that suggests that Si application would contribute to the improvement of Coriander cultivation.

Index Terms—Silicon, Salt stress, *Coriandrum sativum* (L), Tolerance Mechanism, RWC, K^+/Na^+ ratio

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1 INTRODUCTION

Salinity, on a global scale, is a major limiting plant growth and productivity [1], [2]. It affects 20% of the cultivated area around the planet, and 33% of irrigated land, which produces nearly a third of the world's food [3]. Under salinity conditions, about all physiological and biochemical activities in the plant are affected [4]–[6], a reduction in plant growth, inhibition of photosynthesis mechanism, disorganization of stomata closure, decreasing in biomass yield, and imbalance in nutrients concentrations in the plant tissues occur due to water deficit caused by osmotic imbalance [7], [8].

Silicon, the chemical element of atomic number 14 and symbol Si, is a metalloid which represents the most abundant element in the earth's crust after oxygen [9]–[11]. Silicon has been the focus of several studies that have highlighted its beneficial action in agriculture, in improving the tolerance of plants to biotic and abiotic stresses in several crops, and its non-toxic effect [10], [12]–[14]. Plants take up Si in the soluble form of mono-silicic acid, which takes place in low concentrations in the soil solution [15]. Silicon can be accumulated as phytoliths in the cell walls, trichomes, and intracellular spaces attributing to the binding of Si with cell-wall hemicellulose which enhances structural stability for plants and an amorphous silica barrier [16], [17] which can help alleviate both biotic and abiotic stresses [18]. Silicon stimulates many activities for plants, ensuring its resistance to oxidative stress by improving plant defense system such as antioxidant mechanism, it also enhances physiological and biochemical functions and adjusts mineral circulation. Furthermore, Si promotes growth and productivity of plants in a stressful condition [9], [19]–[22].

Coriander *Coriandrum sativum* (L) an herbal plant endemic to Italy, widely cultivated in The Netherlands, Central and Eastern Europe, the Mediterranean (Morocco, Malta, and Egypt), China, India, and Bangladesh. It belongs to the Umbelliferae family, commonly known as kuzbara, kuzbura in the Arab area [23]. It is distinct by its odor, and almost the plant is comestible, seeds and green parts are widely used in different meals. In medicine, coriander presents the properties of diaphoretic, diuretic, carminative and stimulant it has a curative role for digestive respiratory and urinary systems troubles. it emerges a large spectrum of medicinal activities as antioxidant, anti-microbial, antidiabetic, anti-mutagenic, and anthelmintic activities [23]–[25]**.** Coriander is known as a species moderately tolerant to salinity [24], [26], [27].

Promoting the medicinal and aromatic plant (MAP) sector, considering the climate change and the magnitude of the problem of salinity while aiming the sustainability of agriculture are the perspectives of our work aimed to highlight the role of silicon in the increase of salinity tolerance of coriander in salt conditions as an important medicinal and aromatic plant cultivated in Morocco.

2 PROCEDURES

2.1 Plant material and growth conditions

To evaluate the silicon effect on black cumin and coriander under salinity stress conditions, an experiment as RCBD (Randomize Complete Block Design) in three replications was performed in the greenhouse at The National Institute of Agronomic Research –INRA of Agadir. The experimental treatments compromise: salinity at 2 levels 50 mM NaCl, 100

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Mm NaCl with 1 mM of silicon. Irrigation with the different treatments was started when the third leaves appeared, was continued until the end of growth period. Some parameters were measured during experiment time.

2.2 Extraction and determination of proline concentration

Proline contents were measured by the colorimetry method as described by Monneveux and Nemmar [28]. The amount of proline, on a fresh-matter basis of leaves and roots of coriander subjected to salt stress with and without Silicon application, was determined according to a calibration straight graph constructed from a series of standard proline solutions. The optical density of all samples was measured with a spectrophotometer at 528 nm. Each measure was repeated three times to ensure reproducibility of results.

2.3 Determination of chlorophylls content and carotenoids

Chlorophyll extraction was carried out on fresh fully expanded leaf material. 40 mg leaf sample was ground in 80% acetone using a pestle and mortar [29]. The absorbance was measured with a UV/VIS Spectrophotometer and chlorophyll concentrations were calculated using the following formula

Chl a (µg/g FM) = $(12{,}21*A_{663}) – (2{,}81* A_{646}) * V/W$

Chl b (µg/g FM) = $(20{,}13*A_{646}) – (5{,}03*A_{663}) * V/W$

Carotenoids (µg/g FM) = $((1000* A_{470}) – (3{,}27*\text{Chl a}) – (104 *\text{Chl b}))/229$

2.4 Extraction and analyse of mineral elements

After drying, the samples (leaves and roots) were reduced to fine powder. The dry matter/volume ratio is 20 mg of dry matter for 50 ml of a nitric acid 0.5%. Hermetically closed pills to avoid concentration of the extracts by evaporation are stirred periodically 4 to 5 times per day. The extracts were then filtered on filter paper without ash and are therefore ready for the determination of the mineral elements [30]. Na+ and K+ in the sample solution were analyzed using a flame photometer.

2.5 Relative water content RWC

The Relative water content (RWC) measurement allows knowing the relative water content of the plant. The calculation of this value requires the measurement of 3 parameters: fresh mass (FM), imbibed mass (IM) and dry mass (DM). The fresh mass is weighed immediately after harvesting; the imbibed mass is measured after 24h of immersion in distilled water at 4 °C, and the dry mass (DM) is determined after 24 hours of drying the sample in an oven at 80 °C. The RWC is calculated by applying the following formula [31] . The number of plants is five samples for each treatment.

$$RWC = 100 * (FM-DM) / (IM-DM)$$

2.6 Electrolyte leakage EL

100 mg of randomly selected leaf samples, rinsed with distilled water, are placed in 10 ml of distilled water. Then they are incubated at 32 ° C for 2 h, the electrical conductivity (EC) of the bath solution (EC1) was read after incubation. The same samples were then placed in an autoclave at 121 ° C for 20 minutes min to release all electrolytes. The second reading (EC2) was determined after cooling the solution to room temperature [32]. The electrical conductivity is calculated using the formula:

$$EL = EC1 / EC2 \times 100$$

2.7 Total soluble sugar content

Total sugars were determined based on the method of phenol-sulfuric acid and calculated by comparing sample absorbance with a standard glucose curve [33].

2.8 Statistical analysis

Data were subjected to an analysis of variance (ANOVA) using the statistical software Minitab 17, means data were compared by Tukey's test (P≤0,05). the means were then separated by least significant differences (LSD) test at mean data were compared by Tukey's test (P≤0,05).

3 RESULTS

3.1 Effect of Si on the biomass of coriander

In saline conditions, the results obtained in table 1 showed a significant reduction in both aerial part and root biomass of coriander; 50 mM NaCl decreased the aerial fresh biomass by 67% compared to the control, whereas this reduction rate is three times less with 100 mM of NaCl. The fresh root biomass reduced three times less (from 0.67 mg to 0.26 mg) in 100 mM NaCl and half that for the treatment of 50 mM NaCl compared to the control.

As well, remarkable decrease in the dry aerial biomass is obtained with treatment of 100 mM NaCl, it was three times less compared to the control (1.01 mg to 0.28 mg). 50 mM and 100 Mm of NaCl reduced the dry root biomass by 50% compared to the control (0.03 to 0.02 mg).

However, the addition of Si improved these biomasses. For the aerial part, the percentage increase was 60% and 72% for treatments of 50 mM and 100 mM respectively, while the dry weight was enhanced by 59% for 50 mM of NaCl and 84% at 100 mM in comparison with these same conditions of salinity without Si application. Moreover, Si acted positively on the root part, the dry biomass increase was 51% and 70% respectively for 50 mM and 100 mM NaCl treatments compared to the same treatments without Si. For the fresh weight, this improvement was 67% and 60% at mM and 100 mM respectively

Table 1: Fresh and dry biomasses of Coriander under different treatments of NaCl in absence and presence of Silicon (mg).

Parameters → Organ → Treatments ↓		Fresh biomass (mg)		Dry biomass (mg)	
		Aerial part	Roots	Aerial part	Roots
-Si	0 NaCl	4.38±1.64cd	0.67±0.19bc	1.01±0.07cd	0.03±0.01bc
	50 mM NaCl	2.60±0.48de	0.28±0.09c	0.96±0.05cd	0.02±0.01bc
	100 mM NaCl	1.34±0.5e	0.26±0.07c	0.28±0.11d	0.02±0.01c
+Si	0 NaCl	9.58±1.28a	1.81±0.07a	3.43±1.14a	0.07±0.02a
	50 mM NaCl	6.75±1.38b	1.38±0.07ab	2.33±0.41b	0.06±0.01a
	100 mM NaCl	4.87±0.6bc	0.85±0.07bc	1.77±0.37bc	0.05±0.01ab

*Data are expressed as mean values ±SD. Values followed by different letters (a, b and c) in the same column are significantly different at P≤0,05.

3.2 Effect of Si on chlorophyll and carotenoids contents of coriander under different concentration of NaCl

As shown in the Fig.1 salt stress reduced chlorophyll contents, while the application of Si significantly restored chlorophyll levels. 100 mM NaCl significantly reduced the chlorophyll a content twice less than the control treatment. The decrease was 62% for the treatment of 50 mM NaCl. However, Si increased Chlorophyll a and chlorophyll b twice more in all treatments compared to the same treatments of NaCl. As well, carotenoid content decreased in salt conditions. 100 mM NaCl weakened this content with a percentage of 90% in comparison to the control, this percentage was 46% for 50 mM NaCl compared to the control. The Si ameliorated carotenoids, about three times greater in all treatments of Si in comparison with same treatments without Si.

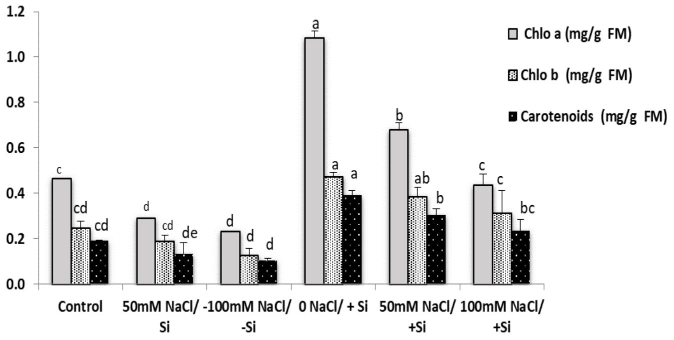


Fig. 1: Chlorophyll and carotenoids content of coriander under different concentration of NaCl with and without Si.

* Data are expressed in mean values ± SD. Bars with different letters show significant differences (a, b, c ...) at P≤0.05 for the same element.

3.3 The effect of Si on soluble sugars and proline contents of coriander under different concentration of NaCl

Table 2 shows that under salt stress the total sugars of coriander are less important than controls for both leaves and roots. In leaves, a reduction of 39% was obtained in 50 mM NaCl and 69% in 100 mM NaCl compared to the control. In roots, this decrease was 33% in 50 mM and 38% in 100 mM NaCl compared to the control. However, the application of Si enhanced total sugars; In leaves, the addition of Si increased the total sugar levels to 37% and 47% respectively for 50 mM and 100 mM NaCl treatments, in comparison to the same treatment of NaCl without Si. Same in root, this increase was 39% and 32% for the 50 mM and 100 treatments respectively.

The proline content of coriander in our six treatments, NaCl affected proline content; 50 mM NaCl increased proline content leaves at 66%, and 73% for the roots compared to the control, as well, 100 mM NaCl increased it at 83% for the leaves and 94% for the roots. However, the Si markedly decreased the accumulation of proline by making its concentration at a level similar to control (Table 2).

Table 2. soluble sugars and proline contents of coriander under different concentration of NaCl under different concentration of NaCl with and without Si

Parameters →		Soluble sugars (mg/g)		Proline (µg/g MF)	
Organ → Treatments ↓		Leaves	Roots	Leaves	Roots
-Si	0 NaCl	99.26±9.13bc	97.50±1.4b	625.49±33.4c	309.80±41.3c
	50 mM NaCl	71.67±2.37cd	73.06±2.37c	1858.82±46.7b	1141.18±32.8b
	100 mM NaCl	58.70±3.06d	70.83±15.04c	3647.06±424a	4823.53±155.6a
+Si	0 NaCl	166.02±15.39a	176.11±3.27a	458.82±77.1c	205.88±27c
	50 mM NaCl	114.35±21.00b	119.44±10.02b	539.22±44.9c	233.33±32.4c
	100 mM NaCl	109.81±3.78b	104.44±7.46b	762.75±103.6c	368.63±91.4c

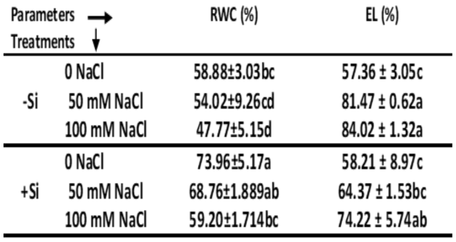
*Data are expressed as mean values ±SD. Values followed by different letters (a, b and c) in the same column are significantly different at P≤0,05.

3.4 The effect of Si on RWC and EL

As shown in Table 3 salt stress minimized the relative content of water of coriander. With 100 mM NaCl, the reduction estimated at 23% compared to the control, 14% for 50 mM NaCl. With the addition of Si, RWC was improved significantly. An increase of 40% in the treatment of Si, 47% in the treatment of 50 mM NaCl compared to the same treatment without Si, and 50% in the treatment of 100 mM NaCl in comparison with the same treatment in the absence of Si.

Salt stress caused an increase in membrane permeability, while Si application restored EL to a level of the control, however the addition of Si to salinity treatments decreased the permeability through increasing EL by 14% for both NaCl concentrations compared to the same treatments without Si (Table 3).

Table 3: RWC and EL of coriander in different concentrations of NaCl with and without Si.



Parameters → Treatments ↓		RWC (%)	EL (%)
-Si	0 NaCl	58.88±3.03bc	57.36 ± 3.05c
	50 mM NaCl	54.02±9.26cd	81.47 ± 0.62a
	100 mM NaCl	47.77±5.15d	84.02 ± 1.32a
+Si	0 NaCl	73.96±5.17a	58.21 ± 8.97c
	50 mM NaCl	68.76±1.889ab	64.37 ± 1.53bc
	100 mM NaCl	59.20±1.714bc	74.22 ± 5.74ab

*Data are expressed as mean values ±SD. Values followed by different letters (a, b and c) in the same column are significantly different at P≤0,05

3.5 The effect of Si on Na+, K+ and k+/Na+ ratio of coriander under different concentration of NaCl

The concentration of sodium in the leaves and roots of coriander was higher in the presence of NaCl, but the application of Si significantly reduced its concentration in saline conditions. The leaves of the plants under 50 mM NaCl showed a concentration 28% higher than the value in the control, and 37% under 100 mM NaCl, however the Si lowered these concentrations by 43% for the treatment of 50 mM NaCl compared to the same treatment without Si, and 53% for the treatment of 100 mM in NaCl compared to the same treatment without Si. For the roots, 50 mM NaCl increased the concentration of Na+ to 23% compared to the control, this increase was 57% for treatment with 100 mM NaCl. while, Si reduced these concentrations to 18% for the treatment of 50 mM and 43% per 100 mM compared to the same treatment in the absence of Si. The Si brought the values of the Na+ closer to the values obtained in the control treatment without NaCl and without Si (Fig. 2; Fig. 3).

Stress conditions decreased potassium levels in leaf and root tissues compared to salt treatments. Potassium concentrations in the leaves and roots increased significantly when Si was added especially to treatments in the presence of NaCl and in the root tissues of coriander. In leaves, a decrease of K+ of 76% and of twice less were obtained respectively in the treatment of 50 mM and 100 Mm compared to the control. However, a significant improvement of 55% and 54% for both treatments of 50 mM NaCl and 100 mM NaCl respectively compared to the same treatments without Si, was obtained. In roots, K+ compared to the control was twice less for both 50 mM NaCl and 100 mM NaCl treatments. While Si increased K+ by 71% in 50 mM NaCl treatment, and 75% 100 mM treatment compared to the same treatments without Si (Fig. 3).

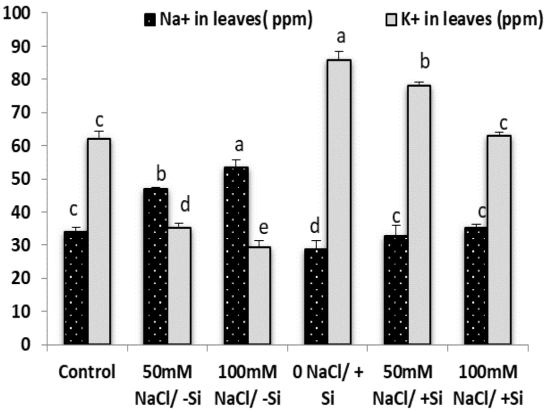


Fig. 2: Na+ and K+ concentrations (ppm) in Leaves of coriander under different treatments of NaCl in absence and presence of Si.

* Data are expressed in mean values ± SD. Bars with different letters show significant differences (a, b, c ...) at P≤0.05 for the same element.

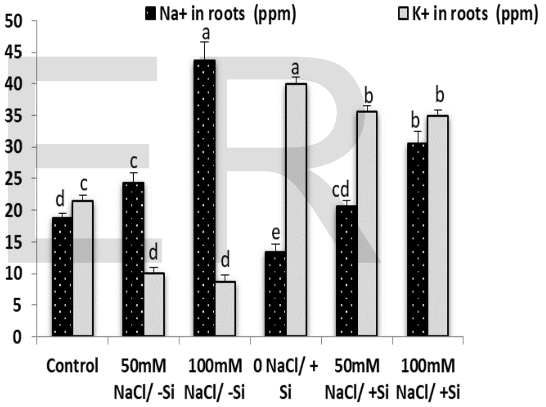


Fig. 3: Na+ and K+ concentrations (ppm) in roots of coriander under different treatments of NaCl in absence and presence of Si.

* Data are expressed in mean values ± SD. Bars with different letters show significant differences (a, b, c ...) at P≤0.05 for the same element.

Salinity affected the K+/Na+ ratio in leaves and roots of coriander. Means less than 1 are obtained in the 50 mM and 100 mM NaCl treatments. Nevertheless, the application of Si significantly improved the K+/Na+ ratio in both roots and leaves. The highest values were obtained in the root tissues, an increase of 76% was observed in the treatment of 100 mM NaCl with Si, and 76% for the treatment of 50 mM with Si, in comparison to same treatments in the absence of Si. At the leaf level, these increases were 69% and 70% respectively for 50 mM and 100 mM NaCl treatments (Fig. 4).

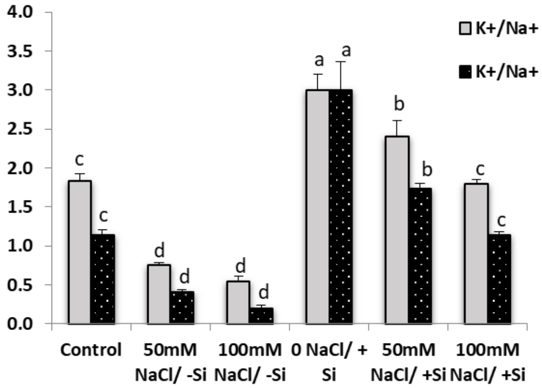


Fig. 4: K+/Na+ ratio in in leaves and roots of coriander under different treatments of NaCl in absence and presence of Si.

* Data are expressed in mean values ± SD. Bars with different letters show significant differences (a, b, c ...) at P≤0.05 for the same element.

4 DISCUSSION

Salinity was known to suppress the plant growth and productivity [1], [2]. Our results showed that concentrations of chlorophyll a, chlorophyll b, and carotenoids decreased with increasing salinity stress for coriander. Whereas, the application of Silicon to our treatments enhanced significantly the content of chlorophyll pigments. Our results are in agreements with the results found Mateos-Naranjo et al. (2013) in their work on the influence of Silicon on the halophytic grass *Spartina densiflora* grew under high salinity; they obtained a significant decrease in the net photosynthetic rate at a high level of salinity, nevertheless, the supply of Si mitigates salt stress [33]. On their work on tomato, Li et al. (2015) affirmed that the Si application augmented chlorophylls and carotenoids contents under salt stress [34]. Likewise, Abdel Latef and Tran 2016 found that Si enhanced the levels of photosynthetic pigments in maize plants exposed to alkaline stress, which could be a consequence of the improvement of leaf area, stimulating so the increase in green pigments per unit area and protection of photosynthetic pigments from reactive oxygen species (ROS) by reinforcing the level of carotenoids, which might have been due to the Silicon-mediated amelioration of oxidative damage and the enhancement of antioxidant defense activity [34], [35].

Under salt conditions, proline content increases in plant tissues in order to resist these stresses [36]. It is well documented the role of proline accumulation in the plant to tolerate salinity [37]. Unlike the above results, the inclusion of Silicon under these conditions of stress decreased remarkably proline contents, same as Abdel Latef and Tran 2016 on their work on maize, they concluded that the decrease of proline concentration might be explained by the action of Si by using other osmoprotective agents to mitigate stress whither important accumulation of proline is not demanded, ensuring to cells high defense [35]. Our data exhibited an increase of total soluble sugar of coriander under salt stress, same as Yin et al (2013) obtained in their work on *Sorghum bicolor,* they reported that Si enhanced total soluble sugar as an a key osmolyte in osmotic adjustment [38].

In our experiment fresh and dry biomasses of coriander decreased significantly when salinity concentration increased, however, applying Si to plants ameliorated the negative impacts of salinity stress on plants biomasses under salt conditions. Our results are in agreements with the results of Ahmad (2014), in his work he found an increase in biomass and grain yield in wheat grown under salt stress and fertilized by K-silicate [39]. As well, Lee et al. (2010) demonstrated that total fresh/dry biomass of soybean (*Glycine max*) plants grown under salt stress (80 mM NaCl) significantly increased [40]. Furthermore, Silicon improved many other crops exposed to different stress such as wheat [41]–[43], chickpea *Cicer arietinum* (L) [44], tomato [45], [46], okra *Abelmoschus esculentus* (L) [47], among others.

Osmotic stress, as an initial step of salt stress, begins instantly when the salt concentration augments to a threshold level at the level of roots, leads secondly to a markedly decrease of leaves growth. Hence, rise above osmotic stress or physiological water deficit is one of the most important strategies of plant adaptation to salt and or salinity stressful environments [7], [48]. It has been reported that Silicon is able to efficiently protect plants from water loss by preventing the transpiration rate [49] or by diminishing water loss via the cuticles due to silica deposition beneath the epidermal cells of leaves and stem [50]. Abbas et al. (2015), Mateos-Naranjo et al. (2013) as well demonstrated that the inclusion of Si significantly increased transpiration rate, number of stomata, and stomatal size in salt-sensitive and salt-tolerant okra plants which ameliorate the water-retention capacity, thus alleviate water stress [33], [47]. Tahir et al. (2012) reported that the relative water content (RWC) was significantly lower in both salt-tolerant and salt sensitive wheat plants grown under high salt stress (100 mM NaCl), while addition of Si completely restored RWC to the levels recorded in the non-stressed plants [42], the same as obtained in our study. Same as Abdel Latef and Tran 2016 found in their work [35].

Under salt stress, the electrolyte leakage increased, while Si decreased it. It is reported that Silicon enhanced growth plant under salt stress by reducing electrolyte leakage. It is suggested that Si decreases plasma membrane permeability and membrane lipid peroxidation and ameliorate membrane integrity , thereby alleviating salt toxicity and improving plant growth [43]

Many studies reported that Si application diminishes Na+ uptake by plants under salt stress and augment K+/Na+ ratio [43], [44], [51], [52]. The obtained results showed that added Si perfectly decreased Na+ concentration in both aerial part and roots of coriander under salt stress and ameliorated significantly the potassium content in aerial parts and roots of salt-stressed plants. It is reported that the Si application reduced transpiration bypass flow in roots and transport of Cl^- to shoots in rice grown in salt stress conditions [53]. Whereas, Liang et al. (2006) showed that the mechanism of increased uptake and transport of K+ and decreased uptake and transport of Na+ from roots to shoots in barley was thought to be attributed to Si-induced stimulation of the root plasma membrane H+-ATPase under salt stress. This was based on evidence that selective uptake and transport of salt ions is largely dependent on the activity of plasma membrane H+-ATPase (proton pump), which is the driving force for ions to be translocated across the membranes and the inhibition of Na+ influx and active Na+ efflux have been proposed as mechanisms of salt tolerance in plants [55]. In their review, Rizwan et al. (2015) reported that Si application improved Na+ binding to leaf cell walls and reduced free Na+ under salt stress, as a conclusion they suggest that Si could ameliorate plant tolerance to salt stress by distributing Na+ in different plant parts [51]. To mitigate salt stress in the plant, Zhu and Gong indicated that Silicon proceeds the aspects of ensuring optimal water content, ameliorating photosynthesis activity and reducing transpiration rate, mitigating ion toxicity so reducing oxidative stress and adjusting biosynthetic solutes and plant hormones [56]. Furthermore, it is reported that under salt stress, Silicon enhanced activities of antioxidant enzymes as well the photochemical efficiency of PSII [46], [57].

4 CONCLUSION

In conclusion of this study, Silicon enhanced the growth of coriander Coriandrum Sativum (L) under salt stress by boosting photosynthetic pigments content, k+ concentrations, and biomass. Sodium transportation into roots and leaves was markedly reduced by added Silicon under salt stress conditions, whereas, leaf and root K+ in salt-stressed plants were very significantly increased by Si application.

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