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Effects of Nano-Silicon Spraying on Physiological Parameters of Bean Varieties Under Saline Stress Conditions

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ABSTRACT

The winter 2022–2023 field experiment in Babil Governorate's Al-Musayyib project region studied how nano-silicon spraying on three bean varieties and sodium chloride salt stress affected crop physiological parameters. A randomized complete block design was used in this factorial experiment with three replications and three factor. The first factor included four Bean varieties were Local, Aquadulce, and Lue Deotono. Second factor was nano-silicon concentrations (0, 2, and 4) ml L^{-1}. The third factor is sodium chloride salt stress (0, 75, 150) mmol L^{-1}. The results showed that the Aquadulce variety was superior in plant height and leaf area, total chlorophyll, peroxidase, and catalase enzyme activity, were 112.76 cm, 3319 cm^2, 17.01 mg 100 g^{-1} fresh weight, 15.32 absorption unit min^{-1} g^{-1}, and 8.58 absorption unit min^{-1} g^{-1}, respectively. As for spraying with nano-silicon, the concentration exceeded (4 ml L^{-1}) for the mentioned characteristics, with averages of 109.58 cm, 3161 cm^2, 18.55 mg 100 g^{-1} fresh weight, 16.89 absorption unit min^{-1} g^{-1}, and 9.10 absorption unit min^{-1} g^{-1}, respectively. It was also noted that salt stress had a significant effect on the traits under study, as the treatment (75 mmol L^{-1}) excelled in the content of proline acid with an average of 1.31 µmol g^{-1}, and the treatment (150 mmol L^{-1}) excelled in the content of the POD and CAT enzymes with averages of 15.67 and 8.76 absorption unit min^{-1} g^{-1}, respectively, it was also observed that the control treatment was superior in the remaining traits.

1. INTRODUCTION

The leguminous plant species known as *Vicia faba* L., commonly referred to as the bean crop, is widely recognized as a significant contributor to the production of vegetable protein that is abundant in amino acids [1]. In recent years, there has been a notable decline in production rates, mostly attributed to the degradation of crop varieties and soil quality caused by elevated saline levels, resulting from high temperatures and low rainfall rates, which leads to faster evaporation of water in these areas, causing a rise in salt concentrations in the soil. In addition, changes in the wind pattern and a decrease in groundwater levels may lead to an increase in the presence of salt water in the soil. These factors combine to contribute to increased salinity in arid and semi-arid regions [2]. There are some things that can affect a plant's growth and development in different ways. Mostly, these things can stop the plant from absorbing nutrients and poison its cells with ions when they are present in high amounts. Plant roots can't receive water because of osmotic pressure, which means that sodium and chlorine ions are present. This makes the salt concentration in the plant sap rise. In turn, this hurts the plant's DNA, which stops it from growing and causes problems with its many functions, like burning leaves and cell walls getting harder because salts build up inside them [3]. Because of this, it is very important to look into new ways to lessen the bad effects of salt stress. Nano-silicon is one way to do this. It strengthens cell walls and makes plants more resistant to or tolerant of salt stress by making antioxidant enzymes work better [4]. Findings from research show that the bean crop is very sensitive to how salty the soil is. To grow this crop successfully, you should choose dirt that has a neutral acidity level and a lot of organic matter. This choice comes from the fact that acidic soil makes root nodules less likely to form [5]. Sodium chloride is a salt that increases the salinity of the earth. This changes the activity of amino acids in plants, which in turn affects how nitrogen is absorbed by the plants and how proteins are created. This action also hinders plant uptake of potassium, calcium, and magnesium. It alters the plant's hormone balance, affecting leaf cell size and longevity [6]. Iraq has poor water supplies, thus choosing the finest salinity-tolerant plant species and purifying the salted water must be done immediately. According to Hasan et al. [7], nano-silicon is a rare and beneficial substance that speeds photosynthesis and improves plant resilience to environmental stresses. Additionally, it boosts a plant's pest and disease resistance. According to Goodwin [8], a small amount of silicon (15 mg L^{-1}) increased legume leaf chlorophyll. If the plant wasn't sprayed, chlorophyll increased from 27.5 mg r $100g^{-1}$ to 42.8 mg r $100g^{-1}$. Bates's [9] study found that proline levels have grown considerably to 0.243 and 0.227 mg g^{-1}. When leaves were treated with nano-silicon at 1.5 and 3 mmol

L^{-1}, proline was lowest (0.135 mg g^{-1}).

Furthermore, the use of nano-silicon shown increased efficacy. The peroxidase enzyme, known as POD, exhibited an absorption of 44.8 units per minute per gram at a concentration of 1.5 mmol L^{-1}. In contrast, the comparison treatment had the lowest average 10.4 units min^{-1} g^{-1}. Furthermore, the findings by Müftügil [10] demonstrated that the application of a 1.5 mmol L^{-1} concentration of nano-silicon resulted in the preservation of proline levels. In comparison to the control treatment, the enzymes peroxidase and catalase exhibited distinct characteristics. Hence, it is imperative to identify novel cultivars that are well-suited to the prevailing environmental conditions and exhibit salt tolerance by means of nano-silicon application and enhancement of the plant's physiological attributes. Hence, the present study was undertaken to ascertain the variety exhibiting the highest salt tolerance and determine the optimal concentration of nano-silicon that enhances the physiological attributes of the crop.

2. MATERIALS AND METHODS

A field experiment was carried out during the winter season 2022-2023 in the Al-Musayyib project area, Babil Governorate, to determine the effect of spraying with nano-silicon on several varieties of beans under salt stress. A randomized complete block design (R.C.B.D) was implemented with three replications in the order of factorial experiments with three factors. The first factor was three concentrations of nano-silicon (0, 2, and 4) ml L^{-1} and symbolized as S0, S1, and S2. The second factor was three concentrations of salt stress (0, 75, and 150) mmol L^{-1}, which are symbolized by R0, R1, and R2, respectively. The third factor is three varieties of beans (local variety, Aquadulce, and Lue Deotono), symbolized by V1, V2, and V3, respectively. The nano-silicon spraying process was carried out twice at the stage of the beginning of flowering and two weeks after the first spraying at the stage of 100% completion of flowering. Two times a week, saline liquids were used to water the plants, and then regular water was used to keep the salt from building up. During the growth time, the plants were kept moist and 100% phosphate fertilizer was added. kg ha-1 in one batch before planting and 10 kg NHA-1 in two batches, one at planting and the second one a month after the first batch [11].

2.1 Studied traits

Plant height (cm): The height was conducted one month following the application of the spray. It involved using a ruler to measure the height from the soil surface to the apex of the main branch.

Leaf area (cm^2): The disc method was employed to compute the leaf area of new leaves, and the estimation of leaf area was conducted one month following the application of the spray.

Proline content (µg g^{-1}): The estimation was conducted as per study [12].

Peroxidase POD (units mg^{-1} min^{-1}): The activity was assessed in accordance with the methodology outlined by Migdadi et al. [13].

Catalase activity (units mg^{-1} min^{-1}): The activity was assessed in accordance with the methodology outlined by Desoky et al. [14].

Chlorophyll content of leaves (mg $100g^1$ fresh weight): It was estimated by taking the weight of the leaves according to the method [15].

2.2 Statistical analysis

The means were examined using the least significant difference (LSD) test and a randomized complete block design (RCBD) with three replicates [16].

3. RESULTS AND DISCUSSION

3.1 Plant height (cm)

The results shown in Table 1 show that there are statistically significant differences in this attribute between the salt stress and nano-silicon stress groups as well as how they interact. The Aquadulce variety (V2) generated the highest average of 112.76 cm, while the local variety (V1) yielded the lowest average of 96.47 cm. The genetic and physiological potential of the Aquadulce variety to benefit from spray treatments has been proven by Qados and Moftah [17], which may explain the diversity in this trait between the varieties. The results showed notable fluctuations in the concentrations of nano-silicon. A concentration of 4 ml L^{-1} (S2) produced an average height of 109.58 cm, while the control treatment of spraying distilled water (S0) produced a minimum height of 98.29 cm. Its vital role accounts for silicon aerosol treatment's superiority at high doses. improving a plant's ability to develop vegetatively by supporting its stems and leaves, maximizing photosynthesis, absorbing light, and promoting the plant's geometric design, among other ways. This aligns with Katerji et al.'s [18] findings. The results shown in the table provide more evidence that the presence or absence of substantial effects depends on the concentration of salt stress. The salt stress treatment (R2) at a concentration of 150 mmol L^{-1} produced the lowest average at 97.02 cm, whereas the comparative treatment without stress (RO) gave the highest average at 110.46 cm. Stress-related factors may be the root of this. Nitrogen fixation is impacted by the salt-induced root nodule bacteria's higher productivity [19]. The outcomes demonstrated a connection between silicon and the different types. The maximum average distance of 117.59 cm was attained by the Aquadulce type with a silicon spray interference treatment concentration of 4 ml L^{-1}. At 83.24 cm, the local variety and the distilled water spraying interference treatment, on the other hand, obtained the least average distance. The outcomes demonstrated how the cultivars responded to salt stress. When salt stress was given at a concentration of 150 mmol L^{-1}, the local variety (V1R2) produced the lowest average distance of 86.92 cm, whereas the Aquadulce variety (V2R0) produced the maximum average distance of 120.96 cm under the intervention therapy without salt stress. The outcomes demonstrated that silicon and salt stress interacted.

With the intervention treatment, which included a concentration of 4 ml L^{-1} silicon spray without salt stress (S2R0), the maximum average height of 116.04 cm was reached. Conversely, the combination of distilled water sprinkling with 150 mmol L^{-1} salt stress was the intervention treatment that resulted in the lowest average height (S0R2). The measurement on average was 90.29 cm. It was clear that the three factors interacted with one another. The Aquadulce variety (V2S2RO) showed the highest average height of

125.81 cm in the silicon spray treatment, with a concentration of 4 ml L^{-1} and no salt stress. However, in the comparable treatment, local diversity was reached at a concentration of 150 mmol L^{-1} when salt stress conditions were met without spraying, with the lowest mean value recorded being 73.59 cm.

Table 1. Effect of varieties, silicon, salt stress, and their interaction on plant height

Silicon	Salt Stress	Varieties			Silicon × Salt Stress
		V 1	V 2	V 3	
	R0	91.92	116.50	114.46	107.63
S 0	R1	84.21	102.88	103.77	96.95
	R2	73.59	103.14	94.14	90.29
	R0	106.07	120.56	96.53	107.72
S 1	R1	103.85	115.76	104.39	108.00
	R2	92.07	103.25	101.91	99.08
	R0	112.84	125.81	109.47	116.04
S 2	R1	108.53	118.10	106.40	111.01
	R2	95.10	108.85	101.11	101.69
L.S.D.			10.59		6.11
Silicon	S 0	83.24	107.51	104,12	98.29
×	S 1	100.66	113.19	100.94	104.93
varieties	S 2	105.49	117.59	105.66	109.58
L.S.D.			6.11		3.53
Salt stress	R0	103.61	120.96	106.82	110.46
×	R1	98.86	112.25	104.85	105.32
Varieties	R2	86.92	105.08	99.05	97.02
L.S.D.			6.11		3.53
Average varieties		96.47	112.76	103.58	
L.S.D.			3.53		

3.2 Leaf area (cm^2)

The findings in Table 2 show that there are notable distinctions in this attribute between the two types—nano-silicon and salt stress—as well as in how they interact. Lue Deotono (V3) had the lowest average (2682 cm^2), while Aquadulce (V2) had the highest (3319 cm^2). A study found that Aquadulce may benefit more from spray treatments due to its genetic and physiological makeup [20]. The results showed considerable nano-silicon concentration variation. Control treatment spraying pure water (S0) produced the lowest average of 2774 cm^2, while 4 ml L^{-1} (S2) provided the greatest average of 3161 cm^2. Because of its significant function, silicon spray therapy is excellent even at high concentrations. improving photosynthesis, improving the geometric structure of the plant, supporting the stems and leaves, and absorbing light are all ways to improve plant growth. According to El-Emary and Amer [21], these variables may have a favorable effect on the vegetative growth characteristics of plants. Table results also indicate the presence of significant repercussions based on salt stress level. At 150 mmol L^{-1}, the salt stress treatment (R2) yielded the lowest average of 2561 cm^2, whereas the control treatment (RO) yielded the highest average of 3389 cm^2. This may be due to the increased focus. In the event that the growth conditions contain sodium ions, the plant will absorb more of them, which will also impact the leaf's area and inhibit the absorption of other ions. The results showed that there was interaction between the variants and silicon. At 4 ml L^{-1}, the silicon spray interference treatment gave the Aquadulce variety the highest average of 3759 cm^2, while the local variety and the distilled water spraying interference treatment yielded the lowest average of 2501 cm^2. The findings demonstrated that there was a relationship between salt stress and the varieties. The Aquadulce variety had the greatest average of 3710 cm^2 during the intervention treatment without stress, whereas the local variety had the lowest average of 2357 cm^2 under the intervention therapy with salt stress at a concentration of 150 mmol L^{-1}. The findings demonstrated a relationship between silicon and salt stress. The greatest average, 3653 cm^2, was obtained from the silicon spray intervention therapy at a concentration of 4 ml L^{-1} without salt stress (S2R0), whereas a lower average was obtained from the distilled water and salt stress intervention treatment at a concentration of 150 mmol L^{-1} (S0R2). The mean was 2487 cm^2. The three components interacted, according to the results. With a concentration of 4 ml L^{-1} and no salt stress, the Aquadulce variety (V2S2RO) exhibited the highest average of 4165 cm^2, whereas the local variety (V1S0R2) was the result of a comparison treatment that did not use silicon spraying and included salt stress at a concentration of 150 mmol L^{-1}. A 2059 cm^2 average was the lowest.

Table 2. Effect of varieties, silicon, salt stress, and their interaction on leaf area

Silicon	Salt Stress	Varieties			Silicon × Salt Stress
		V 1	V 2	V 3	
	R0	3253	3492	3152	3299
S 0	R1	2285	2385	2940	2537
	R2	2059	2678	2723	2487
	R0	3601	3473	2572	3215
S 1	R1	3142	3597	2881	3207
	R2	2633	2970	2368	2657
	R0	3963	4165	2833	3653
S 2	R1	3324	3969	2575	3289
	R2	2377	3144	2095	2539
L.S.D.			562.6		324.8
Silicon	S 0	2532	3126	3221	2774
×	S 1	2852	3346	3759	3026
varieties	S 2	2938	2607	2501	3161
L.S.D.			324.8		187.5
Salt stress	R0	3606	3710	2852	3389
×	R1	2917	3317	2799	3011
Varieties	R2	2357	2931	2395	2561
L.S.D.			324.8		187.5
Average varieties		2960	3319	2682	
L.S.D.			187.5		

3.3 Total chlorophyll content (mg 100 g^1 fresh weight)

The results in Table 3 indicate that there are significant differences for this characteristic between the varieties, nano-silicon, salt stress, and the interaction between them.

The Aquadulce variety gave the highest average, 17.01 mg 100 g^{-1} fresh weight, while the Lue Deotono variety gave the lowest average, 15.70 mg 100 g^{-1} fresh weight. Perhaps the reason for the difference between the varieties in this trait is due to their differences in the nature of growth and their morphological form, as well as the variety's response to the environment is consistent with what it reached [22].

The results showed that there were significant differences between the concentrations of nano-silicon. The concentration of 4 ml L^{-1} (S2) achieved the highest average of 18.55 mg 100 g^{-1} fresh weight, while the control treatment spraying with distilled water (S0) gave the lowest average of 14.33 mg 100 g^{-1} fresh weight. The reason for the superiority of the high-concentration silicon spray treatment is due to its important role in improving plant growth by improving the response of

the leaves and leaflets and providing the best condition for intercepting light radiation by changing the angle of interception, thus increasing the plant's photosynthetic efficiency, and it is consistent with the findings by Selim [23]. The results in the table also indicate the presence of significant effects depending on the concentrations of salt stress. The comparison treatment without stress (RO) gave the highest average of 17.33 mg 100 g^{-1} fresh weight, while the salt stress treatment with a concentration of 150 mmol L^{-1} (R2) gave the lowest average of 15.74 mg 100 g^{-1} fresh weight. This may be due to the effect of salt stress on the activity of root nodule bacteria and the effect on nitrogen fixation.

Table 3. The effect of varieties, silicon, salt stress, and their interaction on the leaves' content of total chlorophyll

Silicon	Salt Stress	Varieties			Silicon × Salt Stress
		V 1	V 2	V 3	
	R0	15.48	16.14	14.39	15.34
S 0	R1	14.51	14.76	13.80	14.36
	R2	13.36	13.77	12.74	13.29
	R0	17.33	17.49	16.43	17.09
S 1	R1	16.30	17.44	15.82	16.52
	R2	15.14	16.44	14.52	15.37
	R0	19.95	20.03	18.68	19.55
S 2	R1	17.84	18.04	16.74	17.54
	R2	18.58	18.94	18.16	18.56
L.S.D.			1.46		0.84
Silicon	S 0	14.45	14.89	13.64	14.33
×	S 1	16.26	17.12	15.59	16.32
varieties	S 2	18.79	19.00	17.86	18.55
L.S.D.			0.84		0.49
salt stress	R0	17.59	17.89	16.50	17.33
×	R1	16.22	16.75	15.45	16.14
varieties	R2	15.69	16.38	15.14	15.74
L.S.D.			0.84		0.49
Average varieties		16.50	17.01	15.70	
L.S.D.			0.49		

The results showed that there was an interaction between the varieties and silicon. The silicon spray intervention treatment at a concentration of 4 ml L^{-1} gave the Aquadulce variety the highest average of 19.00 mg 100 g^{-1} fresh weight, while the spraying intervention treatment with distilled water gave the Lue Deotono variety the lowest average of 13.64 mg 100 g^{-1} fresh weight.

The results showed that there was an interaction between the varieties and salt stress. The intervention treatment without stress gave the variety Aquadulce the highest average of 17.89 mg 100 g^{-1} fresh weight, while the intervention treatment gave salt stress at a concentration of 150 mmol L^{-1}, and the variety Lue Deotono had the lowest average. 15.14 mg 100 g^{-1} fresh weight.

The results showed an interaction between salt stress and silicon. The silicon spray interference treatment at a concentration of 4 ml L^{-1} without salt stress gave the highest average of 19.55 mg 100 g^{-1} fresh weight, while the interaction treatment sprayed with distilled water and salt stress at a concentration of 150 mmol L^{-1} gave the highest average.

The results showed an interaction between the three factors. The silicon spraying treatment at a concentration of 4 ml L^{-1} and without salt stress gave the Aquadulce variety the highest average, amounting to 20.03 mg 100 g^{-1} fresh weight, while the comparison treatment without spraying with salt stress at a concentration of 150 mmol L^{-1} for the variety Lue Deotono the lowest average was 12.74 mg 100 g^{-1} fresh weight.

3.4 Proline content (µmol g^{-1})

The results in Table 4 indicate that there are significant differences for this characteristic between the varieties, nano-silicon, salt stress, and the interaction between them.

Table 4. Effect of varieties, silicon, salt stress, and their interaction on the leaves' content of proline acid

Silicon	Salt Stress	Varieties			Silicon × Salt Stress
		V 1	V 2	V 3	
	R0	0.93	0.93	1.02	0.96
S 0	R1	1.11	1.24	1.08	1.14
	R2	0.90	1.39	1.07	1.12
	R0	1.11	1.29	1.25	1.22
S 1	R1	1.30	1.26	1.45	1.33
	R2	1.05	1.25	1.44	1.24
	R0	1.14	1.34	1.36	1.27
S 2	R1	1.35	1.37	1.60	1.44
	R2	1.43	1.48	1.48	1.46
L.S.D.			0.32		0.19
Silicon	S 0	0.98	1.19	1.06	1.08
×	S 1	1.16	1.27	1.38	1.27
varieties	S 2	1.31	1.40	1.48	1.39
L.S.D.			0.19		0.11
Salt stress	R0	1.06	1.19	1.21	1.15
×	R1	1.26	1.29	1.37	1.31
Varieties	R2	1.12	1.37	1.33	1.28
L.S.D.			0.19		0.11
Average varieties		1.15	1.28	1.31	
L.S.D.			0.11		

The Lue Deotono variety (V3) gave the highest average, 1.31 µmol g^{-1}, while the local variety (V1) gave the lowest average, 1.15 µmol g^{-1}. Perhaps the reason for the difference between the varieties in this trait is due to their difference in the nature of growth and their morphological form, as well as the variety's response to the environment, and it agrees with what was found by Amer and El-Emary [24] who pointed out the difference in response of varieties in their proline content.

The results showed that there were significant differences between the concentrations of nano-silicon. The concentration of 4 ml L^{-1} achieved the highest average of 1.39 µmol g^{-1}, while the control treatment spraying with distilled water (S0) gave the lowest average of 1.08 µmol g^{-1} and is consistent with the findings by Kusvuran et al. [25]. The results in the table also indicate the presence of significant effects depending on the concentrations of salt stress. The salt stress treatment with a concentration of 75 mmol L^{-1} (R1) gave the highest average of 1.31 µmol g^{-1}, while the treatment without stress (RO) gave the lowest average of 1.15 µmol g^{-1}. This may be due to the effect of salt stress on the activity of root nodule bacteria and the effect on nitrogen fixation [26].

The results showed that there was an interaction between the varieties and silicon. The silicon spray interference treatment at a concentration of 4 ml L^{-1} for the Lue Deotono variety gave the highest average of 1.48 µmol g^{-1}, while the spraying interference treatment with distilled water and for the local variety gave the lowest average of 0.98 µmol g^{-1}.

The results showed that there was an interaction between the varieties and salt stress. The interaction treatment with salt stress at a concentration of 150 mmol L^{-1} gave the Aquadulce variety the highest average of 1.37 µmol g^{-1} fresh weight, while the interaction treatment without salt stress and the local variety gave the lowest average of 1.06 µmol g^{-1}.

The results showed an interaction between salt stress and silicon. The silicon spray interaction treatment at a concentration of 4 ml L^{-1} and the salt stress at a concentration of 150 mmol L^{-1} gave the highest average of 1.46 µmol g^{-1}, while the interaction treatment sprayed with distilled water and without salt stress. The lowest average was 0.96 µmol g^{-1}. The results showed an interaction between the three factors. The silicon spray treatment at a concentration of 4 ml L^{-1} with a salt stress at a concentration of 75 µmol g^{-1} for the variety Lue Deotono gave the highest average of 1.60 µmol g^{-1}, while the comparison treatment without spraying and without salt stress gave the highest average. For the local variety (V1S0R0), the lowest average was 0.93 micromol g^{-1}.

3.5 Peroxidase enzyme activity POD (absorption unit min^{-1} g^{-1})

The results in Table 5 indicate that there are significant differences for this characteristic between the variety, nano-silicon, salt stress, and the interaction between them.

The Aquadulce variety gave the highest average of 15.32 (absorption unit min^{-1} g^{-1}), while Lue Deotono (V3) gave the lowest average of 13.48 absorption unit min^{-1} g^{-1}. Perhaps the reason for the difference between the varieties in this trait is due to their difference in the nature of growth and its morphological form, as well as the variety's response to the environment. It is consistent with the findings by Bayat et al. [27], who indicated a difference in the response of varieties in their content of the peroxidase enzyme.

There were big changes between the nano-silicon concentrations, as shown by the results. With an average of 16.89 absorption units min^{-1} g^{-1}, the concentration of 4 ml L^{-1} (S2) was the best. The control method of spraying distilled water (S0) had the lowest average of 11.51 absorption units min^{-1} g^{-1}. This is because In line with what was found by Alharbi et al. [28], this is because silicon plays a big role in the body in making antioxidant enzymes work harder to stop free radicals from doing damage. The table also shows big effects based on how much salt stress there is. It took 15.67 absorption units min^{-1} g^{-1} to absorb 150 mmol L^{-1} of salt stress (R2), while it took 12.74 absorption units min-1 g-1 to absorb stress-free (RO). Higher amounts of antioxidants, like peroxidase enzyme, may keep chloroplasts from breaking down when there is a lot of sodium chloride salt [29]. It was clear from the data that the varieties and silicon worked together. The Aquadulce variety had the highest average absorption rate (17.53 units min^{-1} g^{-1}) when treated with silicon spray interference at a concentration of 4 ml L^{-1}. The Lue Deotono variety had the lowest average absorption rate (10.65 units min^{-1} g^{-1}) when treated with spraying interference with distilled water. The findings showed that the types of plants and salt stress worked together. The variety Aquadulce had the highest average absorption rate (16.26 units min^{-1} g^{-1}) in the interaction treatment with salt stress at a concentration of 150 mmol L^{-1}. The variety Lue Deotono had the lowest average absorption rate (11.85 units min^{-1} g^{-1}) in the intervention treatment without salt stress. Salt stress and silicon were found to work together, as the findings showed. It took 18.41 absorption units min^{-1} g^{-1} on average for the silicon spray interaction treatment with a concentration of 4 ml L^{-1} and the salt stress at a concentration of 150 mmol L^{-1} (S2R2). The other interaction treatment, which used distilled water washing and no salt stress, had the lowest average. The figure that was the lowest was 10.71 absorption units min^{-1} g^{-1}.

Table 5. Effect of varieties, silicon, salt stress and their interaction on the peroxidase enzyme POD

Silicon	Salt Stress	Varieties			Silicon × Salt Stress
		V 1	V 2	V 3	
S 0	R0	10.71	11.58	9.84	10.71
	R1	11.94	13.62	11.18	12.25
	R2	11.35	12.40	10.92	11.56
S 1	R0	12.96	14.18	12.36	13.17
	R1	15.99	15.77	14.56	15.44
	R2	17.77	17.77	15.61	17.05
S 2	R0	14.62	15.11	13.34	14.36
	R1	18.47	18.89	16.32	17.90
	R2	19.44	18.59	17.21	18.41
L.S.D.			2.59		1.49
Silicon × Varieties	S 0	11.33	12.54	10.65	11.51
	S 1	15.57	15.91	14.18	15.22
	S 2	17.51	17.53	15.63	16.89
L.S.D.			1.49		0.86
Salt stress × Varieties	R0	12.76	13.62	11.85	12.74
	R1	15.47	16.10	14.02	15.20
	R2	16.18	16.26	14.58	15.67
L.S.D.			1.49		0.86
Average varieties		14.81	15.32	13.48	
L.S.D.			0.86		

The results showed an interaction between the three factors. The silicon spray treatment at a concentration of 4 ml L^{-1} with salt stress at a concentration of 150 mmol-1 for the variety Aquadulce gave the highest average of 19.44 absorption unit min^{-1} g^{-1}, while the comparison treatment without spraying and without stress gave the highest average. Saline variety Lue Deotono had the lowest average of 9.84 absorption unit min^{-1} g^{-1}.

3.6 Catalase enzyme activity (absorption unit min^{-1} g^{-1})

The results in Table 6 indicate that there are significant differences for this characteristic between varieties, nano-silicon, salt stress, and the interaction between them.

The Aquadulce variety gave the highest average of 8.59 absorption units min^{-1} g^{-1}, while Lue Deotono (V3) gave the lowest average of 7.75 absorption unit min^{-1} g^{-1}. Perhaps the reason for the difference between the varieties in this characteristic is due to the variety's response to the spraying treatments and creating a positive effect in reducing stress damage. salt on the plant, this result is consistent with the findings by Katerji et al. [18].

The results showed that there were significant differences between the concentrations of nano-silicon. The concentration of 4 ml L^{-1} (S2) achieved the highest average of 9.10 absorption unit min^{-1} g^{-1}, while the control treatment spraying with distilled water (S0) gave the lowest average of 7.33 absorption unit min^{-1} g^{-1}. This may be due to the reason for this is the great physiological role that silicon plays in increasing the activity of antioxidant enzymes and reducing the effect of stress resulting from the increased concentration of some elements such as sodium, phosphorus, iron, and nitrogen deficiency [7]. This result is consistent with a study [12]. The results in the table also indicate the presence of significant effects depending on the concentrations of salt stress. The salt stress treatment with a concentration of 150 mmol L^{-1} (R2) gave the highest average of 8.76 absorption unit min^{-1} g^{-1}, while the treatment without stress (RO) gave the lowest

average of 7.51 absorption unit min^{-1} g^{-1}. Because the plant is subjected to high levels of sodium chloride, the production of the peroxidase enzyme goes up. This reduces free radical damage [29]. Results showed silicon's effect on variances. Silicon spray interference at 4 ml L^{-1} had the highest average absorption unit min g-1 for Aquadulce (V2S2). The local variety and distilled water spraying interference treatment had the lowest average absorption unit min g^{-1}. The results showed how salt stress affected plant species. The variety Aquadulce had the highest average absorption rate (9.18 units min^{-1} g^{-1}) in salt stress interaction treatment at 150 mmol L^{-1}. Lue Deotono had the lowest average absorption rate (7.14 units min^{-1} g^{-1}) in the interaction treatment without salt stress. The results showed the interaction between silicon and salt stress. The silicon spray interaction treatment at 4 ml L^{-1} and salt stress at 150 mmol L^{-1} had the greatest average of 10.02 absorption unit min^{-1} g^{-1}, while the interaction treatment with distilled water and no salt stress had the lowest average. Lowest average: 6.35 absorption unit min^{-1} g^{-1}.

Table 6. Effect of species, silicon, salt stress, and their interaction on the enzyme catalase (CAT)

Silicon	Salt Stress	Varieties			Silicon × Salt Stress
		V 1	V 2	V 3	
	R0	6.19	6.84	6.00	6.35
S 0	R1	7.76	7.99	7.08	7.61
	R2	8.18	8.49	7.42	8.03
	R0	7.62	7.97	7.11	7.57
S 1	R1	8.62	8.95	8.28	8.62
	R2	8.22	8.60	7.92	8.25
	R0	8.55	8.98	8.32	8.62
S 2	R1	8.75	8.99	8.28	8.67
	R2	10.28	10.46	9.31	10.02
L.S.D.			0.84		0.48
Silicon	S 0	7.38	7.77	6.83	7.33
×	S 1	8.15	8.51	7.77	8.14
varieties	S 2	9.20	9.48	8.64	9.10
L.S.D.			0.48		0.28
salt stress	R0	7.56	7.93	7.14	7.51
×	R1	8.38	8.64	7.88	8.30
varieties	R2	8.89	9.18	8.21	8.76
L.S.D.			0.48		0.28
Average varieties		8.24	8.58	7.75	
L.S.D.			0.28		

The results showed an interaction between the three factors. The silicon spray treatment at a concentration of 4 ml L^{-1} with salt stress at a concentration of 150 mmol L^{-1} for the variety Aquadulce gave the highest average of 10.46 absorption unit min^{-1} g^{-1}, while the comparison treatment without spraying and without stress gave the highest average. Saline variety Lue Deotono had the lowest average of 6.00 absorption unit min^{-1} g^{-1}.

4. CONCLUSIONS

Based on the present findings, it is evident that the utilization of nanoscale silicon has the potential to enhance the synthesis of antioxidants in various legume cultivars when subjected to salt-induced stress. This phenomenon may have a beneficial impact on the overall capacity and resilience of leguminous plants in mitigating the adverse effects of salt stress.

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