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Physiological responses of *Phaseolus vulgaris* to some Nano bio-stimulants under salt stress conditions

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Abstract

The aim of this study was to evaluate some physiological parameters and biochemical changes in common bean plants (*Phaseolus vulgaris*) as a result of the foliar spraying of some nano stimulants (silicon, polyamine, seaweed and biofertilizer) under salt stress conditions. The pot experiment was conducted in the Agriculture Faculty's greenhouse at Menoufia University in Shibin El-Kom, Egypt during the two summer seasons of 2019 and 2020. Salt stress at level 6 dS/m significantly decreased growth, physiological characteristics, photosynthetic pigments, chemical measurements, and yield parameters. Meanwhile, the use of nano stimulators reduced the adverse effects of salinity by improving water relations, chlorophyll, enzymatic antioxidants (peroxidase and polyphenoloxidase), non-enzymatic antioxidants defense system (carotene, total soluble sugars, total amino acids, and proline), N, P and K and decreased Na+ concentrations resulted in high seed yield, particularly with nano silicon followed by nano biofertilizer. As the level of salinity increased, the seed weight (g/plant) decreased significantly by about 40% at the salt level 6 dS/m. In comparison to the control, using nano silicon resulted in significant increases in the leaf area, relative water content, proline concentration and seed weight by about 84, 53, 49 and 91%, respectively at 6 dS/m salinity level. To mitigate the negative impacts of salinity and improve the production, this study suggests spraying common bean plants with nano silicon followed by nano biofertilizer.

Keywords: salt stress, nano bio stimulators, common bean plants, growth, physiological parameters, chlorophyll concentration, chemical content, yield.

Introduction

Salinity is one of the most harmful non-biological stressors to plants, affecting many agricultural regions throughout the world. More than 20% of all cultivated lands are thought to have excessive salt levels, causing salt stress (Moud and Maghsoudi, 2008). Moreover, salinity has a deleterious impact on plant growth by decreasing leaf water potential, causing morphological and physiological alterations, formation of reactive oxygen species, ion toxicity, and biochemical processes (Khan et al., 2014). *Phaseolus vulgaris* is a substantial source of minerals, vitamins, protein and fiber for a large portion of the human population (Bellucci et al., 2014). However, in *Phaseolus vulgaris*, drought and soil salinity are the primary causes of crop losses. (Kaymakanova, 2009). Nanotechnology is a promising technology in many fields including agriculture (Dimetry and Hussein, 2016). Polyamines (putrescine, spermidine and spermine) are phytohormones that enhanced many physiological processes and help the plant to cope with environmental stresses (Gill and Tuteja., 2010). Although silicon is not an essential mineral, it is involved in a number of metabolic pathways that increase plant tolerance to drought and salinity stress (Flam-Shepherd et al., 2018), as well as increase antioxidant activity and decrease soil pollutant absorption (Rajput et al., 2021). Because their polysaccharide-rich extracts increase seed germination, plant growth, and crop quality, macroalgae (seaweeds) are beneficial for plants (Mzibra et al., 2021). Biofertilizers are natural compounds derived from roots or cropland that include living microorganisms and have no detrimental impact on soil strength or the environment. They play a significant role in atmospheric nitrogen fixation and phosphorus solubilization, as well as the generation of plant hormones, which leads to improved nutrient absorption and drought and moisture stress tolerance. (Aly et al., 2019; El-Beltagi et al., 2020).

Materials and Methods

The present investigation was carried out under greenhouse conditions of the Agriculture Faculty¸ Menoufia University during the 2019 and 2020 summer seasons.

Phaseolus vulgaris (Giza 6) (*Leguminosae*) seed-sowing was carried out on February 20th and 22 at the first and second seasons, respectively in pots containing 14 kg of clay loamy soil. The pot diameter was 40 cm, containing 4 plants. Table (1) shows the physio - chemical parameters of experimental soil according to Page et al. (1982).

Table 1. The physio-chemical characteristics of the soil at the test site.

Texture class	Sand %	Silt %	Clay %	pH	E.C. ds/m	O.M. %	Available nutrients (%)		
							N	P	K
Clay loam	32.02	34.89	31.84	7.88	0.65	1.79	3.14	9.61	3.53

Chloride type of salinization was applied to soil as described by Strogonov (1962) and prepared as salt mixture of NaCl and $CaCl_2$ (2:1 W/W) by adding to each pot to obtain electrical conductivity (E.C.) 0.65 (control), S1 (3 ds/m) and S2 (6 ds/m).

Foliar leaf applications as distilled water (control), nano silicon (nSi) as (SiO_2) (2mM)), nano polyamine "Spermidine" (nPA) (1mM), nano seaweed compound (nSW) (0.5ml/l) contains (seaweeds 7% + salicylic acid 5% + proline 4%) was obtained from Zhengzhou Zheng Shi Chemical Co., Ltd. China. Bio stimulator named Haleax'2; nano biofertilizer (nBio) containing a mixture of nano symbiotic N_2-fixing bacteria of the genera *Azospirillum*, *Azotobacter* and *kelebsilla* were used. The nano bio fertilizer was supplied from biofertilization unit. Plant Pathology Department, Alex. Univ., the (nBio) was used at the rate of 7 g.kg^{-1} seeds. Adequate amount of distilled water to the biofertilizer and added as drench to each seedling in three times at 30, 45 and 60 days after sowing, and control plants treated by adding distilled water. Generally, the size of nano particles was less than 50 nm.

NPK fertilizers added as recommended dose, when necessary, weeds and best management, as well as other agricultural strategies were applied.

Sampling: During the growth periods of both seasons (2019, 2020), samples were taken randomly from each treatment after 60 days after sowing (DAS) to determine data as follows:

1.a. Vegetative growth parameters:

Plant height (cm) and dry weight of total plant all plant pieces were left to dry at 70°C until 72 hours.

Total leaf area (LA) estimated using the dry weight method as suggested by Rhoads and Bloodworth (1964).

Net assimilation rate (NAR), g/cm2/day as described by McCollum (1978). Relative growth rate (RGR) g/day as described by Richards (1969).

Shetty et al. (1995) determined the Salt Tolerance Index (STI) as follows:

Salt tolerance index (STI) $= \frac{DWS \text{ or } DWI}{DWC}$ *Where, DWI, dry weight of stressed plant, DWC, dry weight of unstressed.*

2. Water Relations: Relative water content (RWC) was determined by using the method of Barrs and Weatherley (1962). Membrane Integrity (MI) was determined as described by Sun et al. (2006). The percentage of membrane integrity was calculated as: $(EC_1/EC_2) \times 100$.

3. Biochemical Parameters:

Chlorophyll concentration: was determined using spectrophotometer according to the method described by A.O.A.C (1995) and expressed as mg/g Dr.wt.

Antioxidant enzymes activity: Polyphenol oxidase enzyme activity (PPO) according to the method described by Broesch (1954). Peroxidase enzyme activity (PO) the method described by Fehrmann and Dimond (1967).

Total soluble sugars (TSS) were established spectrocalorimetrically according to the method of Dubois et al. (1956). Total phenols (TP) were established by the method of (Snell and Snell, 1954). Total amino acids determined by using neutral ninhydrin reagent method as described by Rosen (1957). The method of Bates et al. (1973) was used to determine the proline content. N P K were established according to the method described by A.O.A.C. (1995). Sodium concentration was conducted according to Xu and Huang (2006).

4. Yield and its quality, number of pods / plant, seeds weight (g) / plant and seeds weight (kg /Feddan). Seeds protein concentration (%) was determined by using the method of Osborn and Voogt (1978).

Statistical analysis:

The experimental pots were arranged in a complete randomized block design with three replicates. Two–way analysis of variance (ANOVA). The collected data were statistically analyzed using Costat Software (1985).

Heatmap was generated by the software R-4.2.0, 2022 using two packages (heatmap3 and pheatmap). Data for Heatmap was constructed based on standardized data using color scale. As the data were measured in different units, they were standardized by subtracting the average from each value and dividing by the standard deviation of the trait. In the heatmap, the red colour cells show high values, while with blue colour cells show low values of the traits.

Results and discussion

1. Growth characteristics

Table 2 shows growth and physiological parameters in *Phaseolus vulgaris* treated with some nano biostimulators under different levels of salt stress. The results demonstrated that as salt stress increased, growth reduced significantly *($P<0.05$)*. At 6 dS/m salt stress, the dry weight of the whole plant, leaf area and relative growth rate were reduced by around 38, 28 and 14%, respectively, compared to the control at the 1st season. These findings are consistent with those of Zayed et al. (2017) who found a decrease in salt tolerance index, dry weight, and leaf area in *Phaseolus vulgaris* as salt concentration increased. In addition, Bayuelo-Jimenez et al. (2012) found that relative growth rate in *Phaseolus vulgaris* under NaCl stress decreased as salinity increased. The negative effect of salinity on growth may be attributed to decreasing leaf water potential and relative oxygen species, increasing osmotic stress and ion toxicity (Khan et al., 2014), and the harmful effect of hormonal equilibrium (sytocinine/auxines) (Albacete et al., 2008).

In comparison to untreated plants in the 1st season, foliar spraying of nano stimulators on common bean plants enhanced all growth parameters and salt tolerance index, with nano silicon and biofertilizer application showing the greatest increase under normal or salt stress conditions. The 2nd season followed the same pattern. When compared to the control, nano silicon increased the leaf area by about 84 and 76%, respectively, in the 1st and 2nd seasons at 6 dS/m salt stress. Badawy et al. (2021) reported similar results with *Oryza sativa* plants, finding that nano silicon treatment resulted in a highly significant enhancement in plant height, dry matter, and leaf area under salt conditions. The impact of nano silicon in reducing sodium uptake in plants while increasing potassium uptake could explain the improvement in growth parameters (Liang et al., 2005). Rodrigues et al. (2009) also found that silicon improved plant water status and product quality by increasing photosynthesis and decreasing evapo-transpiration. Furthermore, Baniaghil et al. (2013) found that rhizobacteria species such as azotobacter and pseudomonas promoted plant development by regulating oxidative stress enzymes and vital nutrients, as well as increasing proline, chlorophyll, and relative water content under salinity stress (Heidari and Golpayegani, 2012).

Table 2. Effect of salinity, some nano stimulators and their interaction on growth and some physiological characters of *Phaseolus vulgaris* at 60 days after sowing during the two summer seasons 2019 and 2020.

Treatments / Characters		Plant height (cm)		Dry weight of whole plant (g/plant)		Leaf area (cm^2/plant)		Net assimilation rate (cm^2/day)		Relative growth rate (g/ day)		Salt tolerance index	
Salinity (dS/m)	Nano Stimulators	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season2	Season 1	Season 2
S0 (control)		32.7 ^{a}	32.1 ^{a}	4.20 ^{a}	1.14 ^{a}	217.7 ^{a}	214.7 ^{a}	1.02	1.10	30.00	29.00	-	-
S1 (3 dS/m)		29.7 ^{b}	28.3 ^{b}	3.63 ^{b}	3.61 ^{b}	177.0 ^{b}	178.7 ^{b}	0.90	0.90	28.00	24.00	0.80	0.80
S2 (6 dS/m)		26.2 ^{c}	24.8 ^{c}	2.60 ^{b}	2.63 ^{c}	157.6 ^{c}	155.5 ^{c}	0.88	0.80	20.00	22.00	0.60	0.60
	Control	23.7 ^{d}	22.7 ^{d}	2.40 ^{e}	2.40 ^{e}	133.4 ^{e}	140.7 ^{e}	0.60	0.60	32.00	33.00	-	-
	Silicon	34.7 ^{a}	34.2 ^{a}	4.45 ^{a}	4.50 ^{a}	246.1 ^{a}	248.2 ^{a}	1.46	1.45	53.00	53.00	1.70	1.70
	Polyamine	27.6 ^{c}	26.3 ^{c}	2.80 ^{d}	2.84 ^{d}	154.9 ^{d}	149.1 ^{d}	0.86	0.90	34.00	33.00	1.10	1.10
	Seaweed	29.5 ^{c}	28.6 ^{b}	3.63 ^{c}	3.60 ^{c}	175.2 ^{c}	173.4 ^{c}	1.03	1.00	37.00	39.00	1.30	1.30
	Biofertilizer	32.2 ^{b}	30.5 ^{b}	4.02 ^{b}	3.96 ^{b}	210.8 ^{b}	203.4 ^{b}	1.25	1.30	44.00	46.00	1.60	1.60
S0 (Control)	Control	26.9 ^{de}	26.0 ^{def}	3.08 ^{ef}	3.13 ^{de}	152.0 ^{h}	167.8 ^{h}	0.70	0.70	21.00	23.00	-	-
	Silicon	38.0 ^{a}	39.0 a	5.41 ^{a}	5.50 ^{a}	284.3 ^{a}	279.4 ^{a}	1.60	1.70	31.00	36.00	1.90	1.80
	Polyamine	30.4 ^{cd}	29.2 ^{cde}	3.32 ^{de}	3.27 ^{de}	188.4 ^{f}	176.4 ^{g}	0.90	0.95	24.00	27.00	1.10	1.10
	Seaweed	32.5 ^{bc}	32.2 ^{bc}	4.26 ^{bc}	4.24 ^{b}	219.4 ^{c}	213.9 ^{e}	1.20	1.10	25.00	28.00	1.30	1.20
	Biofertilizer	35.8 ^{ab}	34.4 b	4.74 ^{b}	4.55 ^{b}	244.3 ^{b}	235.7 ^{c}	1.40	1.50	29.00	30.00	1.70	1.60
S1 (3 dS/m)	Control	23.9 ^{e}	22.7 ^{gh}	2.69 ^{fg}	2.66 ^{fg}	130.8 ^{k}	134.7 ^{j}	0.50	0.60	14.00	16.00	-	-
	Silicon	35.6 ^{ab}	34.0 ^{b}	4.52 ^{b}	4.51 ^{b}	240.7 ^{b}	246.2 ^{b}	1.40	1.40	24.00	28.00	1.60	1.50
	Polyamine	27.6 ^{de}	26.4 ^{def}	2.93 ^{ef}	3.06 ^{de}	146.4 ^{i}	144.3 ^{i}	0.80	0.72	20.00	18.00	1.10	1.10
	Seaweed	29.4 ^{cd}	28.7 ^{cde}	3.80 ^{cd}	3.64 ^{cd}	166.4 ^{g}	169.9 ^{h}	1.00	1.00	21.00	22.00	1.20	1.10
	Biofertilizer	32.0 ^{bc}	30.0 ^{cd}	4.20 ^{bc}	4.17 ^{bc}	200.6 ^{e}	198.1 ^{f}	1.20	1.30	22.00	23.00	1.50	1.40
S2 (6 dS/m)	Control	20.2 ^{f}	19.0 ^{h}	1.34 ^{h}	1.42 ^{h}	117.4 ^{l}	119.4 ^{l}	0.45	0.43	11.00	12.00	-	-
	Slicon	30.5 ^{cd}	29.5 ^{cd}	3.41 ^{de}	3.44 ^{de}	213.4 ^{d}	218.8 ^{d}	1.20	1.25	22.00	25.00	1.70	1.70
	Polyamine	24.8 ^{e}	23.3 ^{fg}	2.13 ^{g}	2.20 ^{g}	129.9 ^{k}	126.6 ^{k}	0.75	0.65	16.00	17.00	1.10	1.10
	Seaweed	26.7 ^{de}	25.1 ^{efg}	2.83 ^{ef}	2.92 ^{ef}	139.9 ^{j}	136.2 ^{j}	0.80	0.93	18.00	18.00	1.40	1.50
	Biofertilizer	28.9 ^{cd}	27.3 ^{def}	3.11 ^{ef}	3.17 ^{de}	187.5 ^{f}	176.4 ^{g}	1.00	1.05	20.00	20.00	1.60	1.60

* Means superscripted by different alphabetic within each column are significantly different ($P < 0.05$).

**NAR2 and RGR2= Data taken at 60 and 75 days after sowing, All numbers × 10^{-3}*

2. Water relations

The water relations of common bean plants decreased as salt stress increased (Table 3). In the 1st season, compared to the control, there was a 19% decrease in relative water content, and 49% increment in membrane integrity percentage under 6 dS/m salt stress. Similar findings in wheat plants were reported by Mousa et al. (2013). Increased osmotic stress is caused by high salt concentrations in soil solution, which limits plant water absorption, affecting leaf water content, stomatal conductance, and leaf development as a response. (Munns and Tester, 2008).

With nano stimulators application, water relations in common bean leaves significantly improved, the most effective substance was nano silicon followed by nano biofertilizer and finally nano seaweed which improved relative water content by about 51,40 and 21%, respectively compared with the untreated plants in the1st season. In addition, as compared to the control in the 1st season, the application of nano silicon relieved the negative effects of salt stress and raised relative water content by approximately 53% while decreasing membrane integrity percentage by about 33% under 6 dS/m salt stress. The same trend was observed in the 2nd season. These findings are consistent with those of Zayed et al. (2017), who observed a significant decrease in relative water content and an increase in membrane stability in *Phaseolus vulgaris* at all various NaCl concentrations when compared to control. It could be because the nano stimulator increases root hydraulic conductance by increasing the production of plasma-membrane intrinsic protein aquaporins, which could help to increase water intake while reducing oxidative stress and membrane damage (Ali et al., 2021).

Table 3. Effect of salinity, some nano stimulators and their interaction on relative water content, membrane integrity and Chlorophyll concentrations in *Phaseolus vulgaris* at 60 days after sowing during the two summer seasons 2019 and 2020**.**

Treatment	Characters	Relative water content (%)		Membrane integrity (%)		Chlorophyll a		Chlorophyll b		Carotenoids	
		(%)				mg/g DWt.					
Salinity (dS/m)	**Nano Stimulators**	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
S0 (control)		57.62 ^{a}	58.33 ^{a}	19.20^{c}	20.20 ^{c}	6.17 ^{a}	6.15 ^{a}	4.67 ^{a}	4.70 ^{a}	5.34 ^{a}	5.43 ^{a}
S1 (3 dS/m)		51.64 ^{b}	51.24 ^{b}	27.40 ^{b}	27.20 ^{b}	5.17 ^{b}	5.11 ^{b}	3.62 ^{b}	3.74 ^{b}	4.53 ^{b}	4.53 ^{b}
S2 (6 dS/m)		46.57 ^{c}	45.59 ^{c}	34.40^{a}	34.60 ^{a}	4.08 ^{c}	4.03 ^{c}	2.95 ^{b}	3.03 ^{c}	3.90 ^{b}	3.84 ^{b}
	Control	41.43 ^{e}	42.36 ^{d}	32.00 ^{a}	33.00 ^{a}	3.40 ^{c}	3..37 ^{c}	2.36 ^{c}	2.47 ^{c}	2.95 ^{d}	2.87 ^{d}
	Silicon	62.58 ^{a}	62.05 ^{a}	21.7 ^{e}	22.00 ^{e}	6.56 ^{a}	6.47 ^{a}	5.43 ^{a}	5.40 ^{a}	6.76 ^{a}	6.73 ^{a}
	Polyamine	46.23 ^{d}	48.41 ^{c}	29.7 ^{b}	30.00 ^{b}	4.35 ^{bc}	4.33 ^{b}	2.82 ^{bc}	2.92 ^{bc}	3.58 ^{cd}	3.66 ^{cd}
	Seaweed	51.53 ^{c}	50.43 ^{c}	27.33 ^{c}	27.00 ^{c}	5.19 ^{b}	5.15 ^{b}	3.47 ^{b}	2.92 ^{bc}	4.21 ^{c}	4.12 ^{c}
	Biofertilizer	57.94 ^{b}	55.35 ^{b}	24.33 ^{d}	24.70 ^{d}	6.21 ^{a}	6.16 ^{a}	4.64 ^{a}	4.62 ^{a}	5.43 ^{b}	5.63 ^{b}
S0 (Control)	**Control**	47.21^{fg}	50.26^{de}	22.00 ^{g}	23.00 ^{f}	4.21 ^{d}	4.29 ^{c}	2.89 ^{de}	3.00 ^{cd}	3.50 ^{ef}	3.41 ^{de}
	Silicon	70.36 ^{a}	68.82 ^{a}	15.00 ^{i}	16.00 ^{h}	7.95 ^{a}	7.88 ^{a}	6.28 ^{a}	6.24 ^{a}	7.92 ^{a}	7.99 ^{a}
	Polyamine	51.83^{de}	54.28^{cd}	21.00 ^{g}	22.00 ^{f}	4.93 ^{bc}	4.86 ^{bc}	3.80 ^{de}	3.91 ^{cd}	4.18 ^{de}	4.54 ^{bc}
	Seaweed	55.18^{cd}	56.30 ^{c}	20.00^{gh}	21.00^{fg}	6.29 ^{ab}	6.36 ^{ab}	4.45 ^{bc}	4.56 ^{bc}	4.90 ^{bc}	4.85 ^{bc}
	Biofertilizer	63.56 ^{b}	62.00 ^{b}	18.00 ^{h}	19.00 ^{g}	7.49 ^{a}	7.34 ^{a}	5.94 ^{ab}	5.81 ^{ab}	6.23 ^{ab}	6.37 ^{ab}
S1 (3 dS/m)	**Control**	41.10 ^{h}	41.56 ^{g}	32.00^{cd}	33.00 ^{c}	3.82 ^{d}	3.70 ^{cd}	2.30 ^{fg}	2.49 ^{ef}	2.91 ^{ef}	2.80 ^{ef}
	Silicon	62.22 ^{b}	61.14 ^{b}	22.00 ^{g}	23.00 ^{f}	6.62 ^{ab}	6.54 ^{ab}	5.69 ^{ab}	5.66 ^{ab}	6.43 ^{ab}	6.41 ^{ab}
	Polyamine	46.31 ^{g}	48.86^{ef}	30.00^{de}	29.00^{de}	4.29 ^{d}	4.27 ^{c}	2.62 ^{ef}	2.71 ^{de}	4.47 ^{ef}	3.35 ^{de}
	Seaweed	51.17^{de}	50.28^{de}	28.00 ^{e}	27.00 ^{e}	4.94 ^{bc}	4.81 ^{bc}	3.23 ^{de}	3.65 ^{cd}	4.38 ^{cd}	4.20 ^{cd}
	Biofertilizer	57.40 ^{c}	54.40^{cd}	25.00 ^{f}	24.00 ^{f}	6.19 ^{ab}	6.22 ^{ab}	4.25 ^{cd}	4.19 ^{bc}	5.47 ^{bc}	5.92 ^{bc}
S2 (6 dS/m)	**Control**	36.00 i	35.28 ^{h}	42.00 ^{a}	43.00 ^{a}	2.17 ^{e}	2.12 ^{d}	1.89 ^{h}	1.94 ^{f}	2.45 ^{f}	2.41 ^{f}
	Slicon	55.16^{cd}	56.22 ^{c}	28.00 ^{e}	27.00 ^{e}	5.09 ^{bc}	5.00 ^{bc}	4.33 ^{bc}	4.31 ^{bc}	5.94 ^{bc}	5.80 ^{bc}
	Polyamine	40.57 ^{hi}	42.10 ^{g}	38.00 ^{b}	39.00 ^{b}	3.82 ^{de}	3.85 ^{cd}	2.05 ^{gh}	2.14 ^{f}	3.09 ^{ef}	3.10 ^{de}
	Seaweed	48.26^{efg}	44.72^{fg}	34.00 ^{c}	33.00 ^{c}	4.35 ^{cd}	4.27 ^{c}	2.73 ^{de}	2.89 ^{cd}	3.35 ^{ef}	3.31 ^{de}
	Biofertilizer	52.86^{cd}	49.66^{de}	30.00^{de}	31.00^{cd}	4.97 ^{bc}	4.93 ^{bc}	3.74 ^{de}	3.86 ^{cd}	4.61 ^{bc}	4.62 ^{bc}

*Means superscripted by different alphabetic within each column are significantly different ($P < 0.05$).

3. Chemical measurements

3.1. Photosynthetic pigments

As indicated in Table 3, as the salt stress increased, the photosynthetic pigments decreased significantly ($P<0.05$) in common bean. In the 1st season, chlorophyll a and chlorophyll b decreased by 34 and 37%, respectively, under salt stress level 6 dS/m compared to control. Mutale-joan et al. (2021) in tomato plants found similar results. The activity of the chlorophyll degrading enzyme, chlorophyllase, rose in response to salt stress (Nazarbeygi et al., 2011).

Nano stimulators, on the other hand, induced a considerable increase in photosynthetic pigments in common bean under normal or salt stress conditions as compared to the control. In the 1st season, in plants treatment with nano silicon, the increase in chlorophyll a, chlorophyll b, and carotenoids was approximately 135, 129, and 142%, respectively, at a salt level of 6 dS/m. The same trend was encountered in the 2nd season. Similarly, Abou-shlell et al. (2020) reported that photosynthesis pigments were increased in moringa plants affected by NaCl stress after foliar spray with nano-silicon at concentration of 60 mg^{-1} compared to control untreated plants. Because of the improved carbonic anhydrase activity and photosynthetic pigment synthesis, SiO_2 NP treatments significantly increased photosynthesis rates (Siddiqui and Al-Whaibi, 2014).

3.2. Activity of polyphenol oxidase and peroxidase enzymes

Table 4 shows that the antioxidant enzymes activity (polyphenol oxidase and peroxidase) were higher with increasing salinity levels in *Phaseolus vulgaris* plants compared to the control. These results are in accordance with Mutale-joan et al. (2021) who reported similar findings in tomato plants.

In most plants, increased activity of the antioxidant enzymes is thought to constitute a salt tolerance mechanism (Hu et.al., 2012). When applied to common bean plants in normal and salt conditions, the nano stimulators (silicon, polyamine, seaweed, and biofertilizer) increased antioxidant enzyme activity compared to the control. The plants treated by nano silicon and biofertilizer showed an increase in polyphenol oxidase and peroxidase enzymes by about 149 and 120%, respectively under 6 dS/m salt level compared with the untreated plants. Similarly, Gou et al. (2020) found that adding silicon to cucumber seedlings increased the superoxide dismutase and catalase activities under salt stress compared with the control.

Table 4. Effect of salinity, some nano stimulators and their interaction on biochemical changes in *Phaseolus vulgaris* at 60 days after sowing during the two summer seasons 2019 and 2020.

Treatments / Characters		Polyphenol oxidase (OD after 45 min/g fr.wt.)		Peroxidase (after 2 min / g fr.wt)		Total soluble sugars (mg/g Dwt.)		Total amino acids (mg leucin /gm Dwt. leaves)		Proline (µg/g Dwt.)	
Salinity (dS/m)	**Nano Stimulators**	Season$_1$	Season$_2$	Season$_1$	Season$_2$	Season$_1$	Season$_2$	Season$_1$	Season$_2$	Season$_1$	Season$_2$
S0 (control)		0.43 ^{c}	0.43 ^{c}	0.42 ^{c}	0.43 ^{c}	28.3 ^{a}	29.0 ^{a}	20.44 ^{c}	18.97 ^{c}	173.10 ^{c}	176.17 ^{c}
S1 (3 dS/m)		0.52 ^{b}	0.52 ^{b}	0.53 ^{b}	0.54 ^{b}	23.8 ^{b}	23.1 ^{b}	23.19 ^{b}	24.42 ^{b}	228.47 ^{b}	230.56 ^{b}
S2 (6 dS/m)		0.63 ^{a}	0.63 ^{a}	0.72 ^{a}	0.72 ^{a}	15.7 ^{c}	16.6 ^{c}	29.31 ^{a}	29.54 ^{a}	308.14 ^{a}	304.66 ^{a}
	Control	0.30 ^{e}	0.30 ^{e}	0.34 ^{e}	0.35 ^{e}	15.4 ^{d}	15.4 ^{d}	18.87 ^{c}	18.21 ^{e}	192.41 ^{e}	191.92 ^{e}
	Silicon	0.73 ^{a}	0.73 ^{a}	0.75 ^{a}	0.76 ^{a}	28.8 ^{a}	30.1 ^{a}	32.41 ^{a}	31.15 ^{a}	292.50 ^{a}	294.80 ^{a}
	Polyamine	0.43 ^{d}	0.43 ^{d}	0.45 ^{d}	0.45 ^{d}	19.2 ^{c}	20.6 ^{c}	20.83 ^{b}	19.25 ^{d}	211.84 ^{e}	217.92 ^{e}
	Seaweed	0.54 ^{c}	0.54 ^{c}	0.59 ^{c}	0.58 ^{c}	22.6 ^{b}	22.5 ^{c}	27.94 ^{a}	27.20 ^{b}	232.00 ^{c}	253.13 ^{b}
	Biofertilizer	0.64 ^{b}	0.64 ^{b}	0.67 ^{b}	0.66 ^{b}	27.0 ^{a}	28.8 ^{b}	23.60 ^{b}	25.05 ^{c}	254.10 ^{b}	228.70 ^{c}
S0 (Control)	**Control**	0.25 ^{j}	0.25 ^{h}	0.28 ^{h}	0.27 ^{h}	20.7 ^{ef}	20.0 ^{fg}	17.20 ^{g}	15.50 ^{h}	137.80 ^{n}	141.15^{m}
	Silicon	0.59 ^{de}	0.59 ^{cd}	0.55 ^{de}	0.55 ^{de}	35.0 ^{a}	39.2 ^{a}	23.95 ^{ef}	22.60 ^{e}	211.20 ^{i}	219.40^{gh}
	Polyamine	0.34 ^{hi}	0.34 ^{g}	0.35 ^{g}	0.36 ^{g}	24.6 ^{cd}	25.9 ^{cd}	17.55 ^{j}	16.60 ^{h}	154.61 ^{m}	158.70 ^{l}
	Seaweed	0.43 ^{g}	0.43 ^{f}	0.44 ^{f}	0.43 ^{f}	27.5 ^{bc}	28.5 ^{bc}	21.91^{fgh}	19.90 ^{fg}	193.16 ^{j}	190.70 ^{i}
	Biofertilizer	0.54 ^{f}	0.54 ^{e}	0.52 ^{e}	0.53 ^{e}	33.8 ^{a}	31.3 ^{b}	21.60 ^{gh}	20.25 ^{fg}	158.70 ^{l}	170.90 ^{k}
S1 (3 dS/m)	**Control**	0.30 ^{i}	0.30 ^{gh}	0.32^{gh}	0.33 ^{g}	15.3 ^{gh}	14.4 ^{hi}	18.90 ^{ig}	18.55 ^{g}	184.23 ^{k}	182.20 ^{j}
	Silicon	0.73 ^{b}	0.73 ^{b}	0.75 ^{c}	0.77 ^{c}	31.1 ^{ab}	29.0 ^{bc}	25.65 ^{e}	30.35 ^{c}	285.30 ^{d}	288.20 ^{c}
	Polyamine	0.43 ^{g}	0.43 ^{f}	0.42 ^{f}	0.43 ^{f}	20.0 ^{ef}	21.6 ^{ef}	20.17 ^{hi}	20.25 f^{g}	210.20 ^{i}	223.70 ^{g}
	Seaweed	0.55 ^{ef}	0.55 ^{de}	0.57 ^{de}	0.55 ^{de}	239 ^{de}	23.0 ^{de}	31.00 ^{c}	27.95 ^{d}	235.90 ^{g}	218.10 ^{h}
	Biofertilizer	0.61 ^{cd}	0.61 ^{cd}	0.61 ^{d}	0.60 ^{d}	28.9 ^{bc}	27.3 ^{bc}	20.25 ^{hi}	25.00 ^{d}	226.70 ^{h}	240.60 ^{f}
S2 (6 dS/m)	**Control**	0.35 ^{h}	0.35 ^{g}	0.43 ^{f}	0.45 ^{f}	10.3 ^{i}	11.9 ^{i}	20.25 ^{hi}	20.85 ^{f}	255.20 ^{f}	252.40 ^{e}
	Slicon	0.87 ^{a}	0.87 ^{a}	0.94 ^{a}	0.95 ^{a}	20.3 ^{ef}	22.1 ^{ef}	39.70 ^{a}	40.50 ^{a}	381.00 ^{a}	376.80 ^{a}
	Polyamine	0.53 ^{f}	0.53 ^{e}	0.57 ^{de}	0.56 ^{de}	13.1 ^{hi}	14.4 ^{hi}	22.95 ^{fg}	23.00 ^{e}	270.70 ^{e}	274.50 ^{d}
	Seaweed	0.65 ^{c}	0.65 ^{c}	0.77 ^{c}	0.77 ^{c}	16.3 ^{gh}	16.1 ^{gh}	35.00 ^{b}	34.35 ^{b}	333.20 ^{b}	328.10 ^{b}
	Biofertilizer	0.77 ^{b}	0.77 ^{b}	0.87 ^{b}	0.85 ^{b}	18.36 ^{fg}	18.7 ^{fg}	28.65 ^{d}	29.30 ^{c}	300.60 ^{c}	291.50 ^{c}

* Means superscripted by different alphabetic within each column are significantly different ($P < 0.05$).

3.3. Total soluble sugars, total free amino acids and proline concentrations

Total soluble sugars decreased when salt levels increased in both the 1st and 2nd seasons, as shown in Table 4, whereas total free amino acids and proline concentrations increased. At a salt stress level of 6 dS/m, the reduction in total soluble sugars was around 45%, while the increase in total free amino acids and proline were about 43 and 78%, respectively, when compared to the control. Similar findings were reported by (Taïbi et al., 2021) in *Phaseolus vulgaris* plants. In comparison to the untreated control plants, nano stimulators treatment resulted in significant increases in total soluble sugars, total free amino acids, and proline, with increases of about 87, 72, and 52%, respectively in common bean plants. Additionally, under all salinity levels in the 1st season, nano silicon treatment had a favourable influence on total soluble sugars, total free amino acids, and proline content. The 2nd season followed the same pattern. These findings are consistent with Qados (2015) who found that nano silicon treatment enhanced the level of soluble sugars and proline in faba bean plants under NaCl stress.

There is a strong relationship between the accumulation of soluble sugar and proline with the osmotic stress tolerance. When a number of glycophytes were exposed to salt stress, the enhancing effect of silicon on soluble sugars and proline was found to be the principal organic osmotic (Hassanein et al., 2012).

3.4. Mineral concentrations

As indicated in Table 5, the minerals concentrations reduced as the salinity stress increased. In the 1st season, the concentrations of N, P, and K in common bean declined by about 19, 25 and 19%, respectively, while the Na^+ content increased by around 116% under 6 dS/m salt stress. These results are similar to those of Taïbi et al. (2021), on *Phaseolus vulgaris*. The increase in membrane integrity percentage is thought to be the cause of salt stress's negative influence on nutrient uptake (Table 3). The application of nano stimulators in the 1st season, on the other hand, resulted in a considerable increase in the concentration of all minerals under normal and salt stress conditions. Under 6 dS/m, the nano silicon had the maximum increase in N, P, and K concentrations of 42, 80, and 81%, respectively, whereas the Na^+ concentration declined.

Table 5. Effect of salinity, some nano stimulators and their interaction on some elements concentration of *Phaseolus vulgaris* at 60 days after sowing during the two summer seasons 2019 and 2020.

Treatments / Characters		(N %)		(P %)		(K %)		(Na %)		Na^+/K^+ ratio	
Salinity (dS/m)	**Nano Stimulators**	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
S0 (control)		3.11^{a}	3.06^{a}	0.36^{a}	0.34^{a}	3.06^{a}	3.07^{a}	0.32^{c}	0.33^{c}	0.11^{c}	0.12^{c}
S1 (3 dS/m)		2.82^{a}	2.71^{b}	0.32^{b}	0.31^{b}	2.85^{ab}	2.83^{a}	0.49^{b}	0.45^{b}	0.18^{b}	0.17^{b}
S2 (6 dS/m)		2.51^{b}	2.41^{c}	0.27^{c}	0.27^{c}	2.48^{b}	2.37^{b}	0.69^{a}	0.70^{a}	0.28^{a}	0.33^{a}
	Control	2.68^{c}	2.07^{c}	0.26^{d}	0.25^{d}	2.09^{c}	2.04^{d}	0.69^{a}	0.71^{a}	0.35^{a}	0.37^{a}
	Silicon	3.24^{a}	3.32^{a}	0.39^{a}	0.38^{ab}	3.37^{a}	3.36^{a}	0.33^{c}	0.33^{c}	0.10^{d}	0.10^{d}
	Polyamine	3.05^{bc}	2.16^{c}	028^{d}	0.28^{c}	2.62^{b}	2.48^{c}	0.56^{b}	0.61^{a}	0.22^{b}	0.26^{b}
	Seaweed	2.91^{a}	2.95^{b}	0.31^{c}	0.30^{c}	2.85^{b}	2.87^{b}	0.49^{b}	0.47^{b}	0.18^{c}	0.17^{c}
	Biofertilizer	3.14^{a}	3.12^{ab}	0.36^{b}	0.34^{bc}	3.05^{ab}	3.04^{ab}	0.34^{c}	0.35^{c}	0.12^{d}	0.13^{d}
S0 (Control)	**Control**	2.55^{bcd}	2.33^{efg}	0.30^{fg}	0.29^{def}	2.38^{bcd}	2.31^{def}	0.54^{cde}	0.56^{cde}	0.23^{de}	0.24^{cde}
	Silicon	3.58^{a}	3.84^{a}	0.43^{a}	0.41^{a}	3.55^{a}	3.69^{a}	0.20^{f}	0.20 i	0.06^{i}	0.05^{j}
	Polyamine	2.78^{abc}	2.37^{efg}	0.32^{def}	0.31^{cde}	2.86^{abc}	2.75^{bcd}	0.43^{de}	0.43^{def}	0.15^{fg}	0.16^{fgh}
	Seaweed	3.20^{ab}	3.26^{abc}	0.35^{cde}	0.33^{cd}	3.11^{ab}	3.14^{abc}	0.22^{f}	0.25^{ghi}	0.07^{hi}	0.08^{ij}
	Biofertilizer	3.43^{a}	3.48^{ab}	0.40^{ab}	0.38^{ab}	3.38^{ab}	3.48^{a}	0.21^{f}	0.23^{hi}	0.06^{i}	0.07^{j}
S1 (3 dS/m)	**Control**	2.20^{cd}	2.00^{g}	0.27^{gh}	0.26^{fg}	2.11^{cd}	3.48^{a}	0.65^{bc}	0.59^{cd}	0.31^{bc}	0.27^{cd}
	Silicon	3.23^{ab}	3.20^{bc}	0.39^{abc}	0.38^{ab}	3.36^{ab}	3.31^{ab}	0.37^{ef}	0.34^{fgh}	0.11^{ghi}	0.10^{hij}
	Polyamine	2.53^{bcd}	2.12^{fg}	0.28^{fgh}	0.29^{def}	2.63^{abc}	2.58^{cde}	0.44^{de}	0.53^{cde}	0.17^{efg}	0.21^{def}
	Seaweed	3.00^{ab}	3.08^{bcd}	0.32^{def}	0.30^{cde}	3.00^{abc}	3.01^{abc}	0.59^{cd}	0.45^{def}	0.20^{ef}	0.15^{fgh}
	Biofertilizer	3.15^{ab}	3.13^{bcd}	0.36^{bcd}	0.33^{cd}	3.16^{ab}	3.10^{abc}	0.39^{def}	0.36^{efg}	0.12^{ghi}	0.12^{ghi}
S2 (6 dS/m)	**Control**	2.06^{d}	1.89^{g}	0.20^{i}	0.21^{h}	1.78^{d}	1.65^{f}	0.89^{a}	0.98^{a}	0.50^{a}	0.59^{a}
	Slicon	2.92^{abc}	2.91^{bcd}	0.36^{bcd}	0.34^{bc}	3.22^{ab}	3.10^{abc}	0.42^{de}	0.46^{def}	0.13^{gh}	0.15^{fgh}
	Polyamine	2.18^{cd}	2.00^{g}	0.24^{hi}	0.24^{gh}	2.38^{bcd}	2.13^{ef}	0.80^{ab}	0.88^{ab}	0.34^{b}	0.41^{b}
	Seaweed	2.53^{bcd}	2.52^{def}	0.27^{gh}	0.28^{efg}	2.44^{bcd}	2.46^{cde}	0.65^{bc}	0.72^{bc}	0.27^{cd}	0.29^{c}
	Biofertilizer	2.85^{abc}	2.75^{cde}	0.31^{efg}	0.30^{cde}	2.60^{abc}	2.54^{cde}	0.43^{de}	0.47^{def}	0.17^{efg}	0.19^{efg}

* Means superscripted by different alphabetic within each column are significantly different ($P < 0.05$).

In the 2nd season, similar results were observed. Badawy et al. (2021) found that nano-silicon foliar spray or soaking grains increased K^+ and K^+/Na^+ ratio and decreased Na^+ concentration in *Oryza sativa* affected by NaCl stress. Under salt stress, this reduction in Na^+ absorption in barley plants could be attributable to Si-mediated activation of the root plasma membrane H^+-ATPase activity (Liang et al., 2007).

4. Yield components

Table 6 demonstrates that as salt stress increased, yield components in common bean plants decreased dramatically in comparison to the control. In the 1st and 2nd seasons, seed weight (g/plant) decreased by 40 and 38%, respectively, as compared to control at a salinity level of 6 dS/m. These findings are in agreement with those of Mousa et al. (2013) in wheat plants. Nano stimulators (silicon, polyamine, seaweed, and biofertilizer) on the other hand, resulted in a significant increase in yield components in common bean plants. Under 6 dS/m salt level, nano silicon application produced the best results, with a 91% increase in seed weight (g/plant) and a 36% increase in seed protein percentage, respectively, when compared to controls in the 1st season. The same trend was observed in the 2nd season. Similarly, Khalifa et al. (2016) reported that foliar silicon administration at 2 mM resulted in the greatest increase in lettuce plant head weight and size, followed by silicon at 1 mM. As shown in the current study, the increase in yield of common bean plants treated with nano stimulator could be due to improvements in total water content, membrane integrity, photosynthetic pigments, enzymatic antioxidants (peroxidase and polyphenoloxidase) and non-enzymatic antioxidants defense system (carotene, total soluble sugars, total amino acids, and proline), N, P, K and decreased Na+ concentrations which improved seed yield of plants. In this respect, Javaid et al. (2019) reported that nano stimulators had desired effects on plants by improving water relations, phytopigments, regulating oxidative stress enzymes and essential nutrients, accumulation of soluble sugar, and proline as an osmoregulatory of the stressed plants.

Table 6. Effect of salinity, some nano stimulators and their interaction on the yield components of *Phaseolus vulgaris* at harvesting stage during the two summer seasons 2019 and 2020.

Treatments \ Characters		Pods Number / plant		Seed weight (g /plant)		Seed weight (kg/ Feddan)		Seeds protein (%)	
Salinity (dS/m)	**Nano Stimulators**	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
S0 (control)		4.0 ^{a}	4.3 ^{a}	12.5 ^{a}	12.0 ^{a}	726.4 ^{a}	695.8 ^{a}	15.54 ^{a}	15.7 ^{a}
S1 (3 dS/m)		3.2 ^{b}	3.5 ^{b}	9.9 ^{b}	9.4 ^{b}	461.2 ^{b}	440.3 ^{b}	14.34 ^{a}	14.4 ^{a}
S2 (6 dS/m)		2.0 ^{b}	2.5 ^{c}	7.5 ^{c}	7.4 ^{c}	258.0 ^{c}	251.3 ^{c}	11.82 ^{b}	11.7 ^{b}
	Control	2.3 ^{c}	2.1 ^{c}	6.7 ^{d}	7.0 ^{c}	227.2 ^{e}	238.5 ^{e}	11.7 ^{c}	11.7 ^{b}
	Silicon	4.7 ^{a}	5.3 ^{a}	14.8 ^{a}	13.7 ^{a}	849.0 ^{a}	789.5 ^{a}	16.6 ^{a}	16.6 ^{ab}
	Polyamine	2.3 ^{c}	2.7 ^{c}	7.5 ^{d}	7.0 ^{c}	320.2 ^{d}	301.0 ^{d}	12.8 ^{bc}	13.0 ^{b}
	Seaweed	3.0 ^{bc}	3.1 ^{bc}	9.2 ^{c}	9.0 ^{cd}	433.3 ^{c}	426.4 ^{c}	14.8 ^{ab}	14.8 ^{ab}
	Biofertilizer	3.7 ^{b}	4.0 ^{b}	11.7 ^{b}	11.3 ^{b}	579.6 ^{b}	557.0 ^{b}	13.6 ^{bc}	13.6 ^{ab}
S0 (Control)	**Control**	3.0 ^{cd}	3.0 ^{cd}	8.5 ^{ef}	9.0 ^{cd}	378.0 ^{h}	401.6 ^{ef}	14.3 ^{ab}	14.8 ^{ab}
	Silicon	6.0 ^{a}	7.0 ^{a}	19.5 ^{a}	18.0 ^{a}	1280.5 ^{a}	1189.1 ^{a}	18.1 ^{a}	18.3 ^{a}
	Polyamine	3.0 ^{cd}	3.0 ^{cd}	9.0 ^{de}	9.0 ^{cd}	451.9 ^{fg}	451.9 ^{e}	13.2 ^{bc}	13.5 ^{ab}
	Seaweed	4.0 ^{bc}	4.0 ^{bc}	12.0 ^{bc}	12.0 ^{bc}	667.2 ^{d}	667.2 ^{c}	16.4 ^{ab}	16.6 ^{ab}
	Biofertilizer	4.0 ^{bc}	5.0 ^{ab}	13.5 ^{bc}	12.0 ^{bc}	854.6 ^{b}	769.1 ^{b}	15.7 ^{ab}	15.4 ^{ab}
S1 (3 dS/m)	**Control**	2.0 ^{d}	2.0 ^{d}	6.0 f^{g}	6.0 ^{d}	201.4 ^{j}	201.4 ^{ij}	13.2 ^{bc}	13.5 ^{ab}
	Silicon	5.0 ^{ab}	5.0 ^{b}	14.5 ^{b}	14.0 ^{b}	776.2 ^{d}	750.3 ^{b}	17.2 ^{ab}	17.3 ^{ab}
	Polyamine	2.0 ^{d}	3.0 ^{cd}	7.5 ^{ef}	6.0 ^{d}	346.4 ^{hi}	288.6 ^{h}	11.5^{de}	11.5 ^{cd}
	Seaweed	3.0 ^{cd}	3.0 ^{bc}	9.5 ^{de}	9.0 ^{cd}	417.3 ^{g}	396.4 ^{f}	15.4 ^{ab}	15.2 ^{ab}
	Biofertilizer	4.0 ^{bc}	4.0 ^{bc}	12.0 ^{bc}	15.0 ^{bc}	564.9 ^{e}	564.9 ^{d}	14.1 ^{ab}	14.3 ^{ab}
S2 (6 dS/m)	**Control**	2.0 ^{d}	2.0 ^{d}	5.5 ^{g}	6.0 ^{d}	102.2 ^{l}	112.5 ^{k}	10.7 ^{f}	10.7 ^{d}
	Slicon	3.0 ^{cd}	4.0 ^{bc}	10.5 ^{cd}	9.0 ^{cd}	490.4 ^{f}	429.1 ^{ef}	14.5 ^{ab}	14.1 ^{ab}
	Polyamine	2.0 ^{d}	2.0 ^{d}	6.0 ^{fg}	6.0 ^{d}	162.4 ^{k}	162.4 ^{j}	10.8 ^{ef}	10.2 ^{d}
	Seaweed	2.0 ^{d}	2.0 ^{d}	6.0 ^{fg}	6.0 ^{d}	215.5 ^{j}	215.5 ^{i}	12.6 ^{cd}	12.5 ^{bc}
	Biofertilizer	3.0 ^{cd}	3.0 ^{cd}	9.5 ^{de}	10.0 ^{bc}	319.3 ^{i}	337.0 ^{g}	11.1 ^{ef}	11.2 ^{cd}

* Means superscripted by different alphabetic within each column are significantly different ($P < 0.05$).

5. Heatmap analysis

Figure (1) shows heatmap of the relationship between the treatments and the studied traits (Dry weight of whole plant (DWW), Leaf area (LA), Relative water content (RWC), Membrane integrity (MI), Chl_a and b, Polyphenol oxidase (PO), Peroxidase (Pero), Total soluble sugars (TSS), Proline, N, P, Na+/K+ ratio, Seed weight (Kg/Feddan) (SW) and Seed protein).

From the heatmap in Figure (1), it was observed that high values of DWW, LA, RWC, Chl_a, Chl. b, N, P, Na+/K+ ratio, SW and Seed protein of common bean plants (orange color) were found in S0 (control) with nano silicon treatment, while the low values (blue color) were found in the treatment of S2 (6 dS/m). The highest values of TSS in shoot were found in S1(3 dS/m) with nano seaweed treatment, while the lowest values were found in the treatment of S2 (6 dS/m) without nano stimulators. The highest values of PO, Pero and proline were in S2 (6 dS/m) with nano silicon treatment, while the lowest values were in the treatment of S0 (control). The highest values of MI and Na+/K+ ratio were found in the treatment S2 (6 dS/m), while the lowest values were found in S0 (control) with nano silicon treatment. In conclusion, the application of nano silicon was more effective under normal and salt stress conditions.

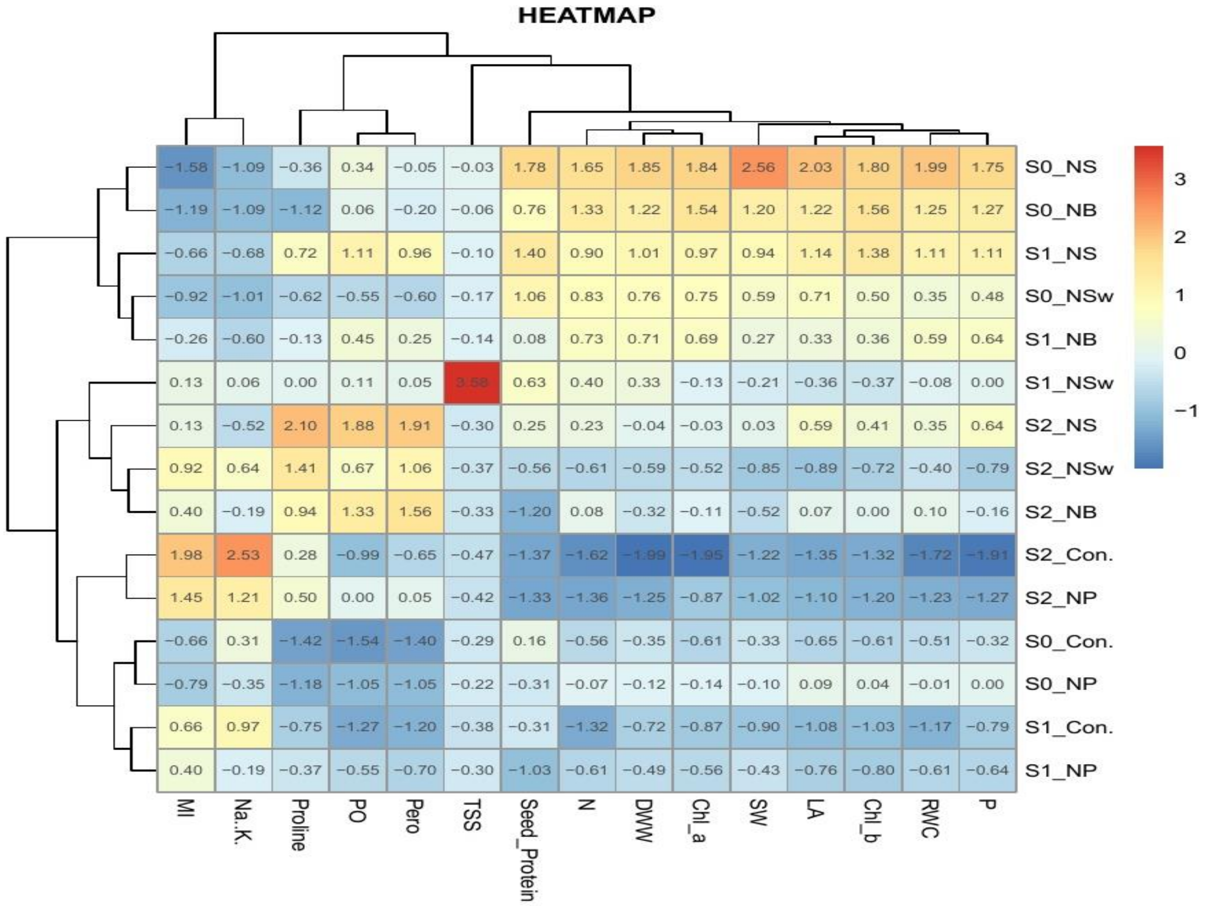

Figure (1): Heatmap summarizing the relationship between the treatments and the studied traits (Dry weight of whole plant (DWW), Leaf area (LA), Relative water content (RWC), Membrane integrity (MI), Chlorophyll a (Chl_a) and Chlorophyll b (Chl_b), Polyphenol oxidase (PO), Peroxidase (Pero), Total soluble sugars (TSS), Proline, N, P, Na+/K+ ratio, Seed weight (Kg/Feddan) (SW) and Seed protein) of *Phaseolus vulgaris* at 60 days after sowing during the two summer seasons 2019 and 2020. S0(control), S1(3 dS/m), S2 (6 dS/m), NS (Nano Silicon), NP (Nano Polyamine), NSw (Nano Seaweed) and NB (Nano Biofertilizer).

Conclusion

The current study examined the effects of high salinity stress on common bean plants, as well as the potential application of engineered nano stimulator particles (silicon, polyamine, seaweed, and biofertilizer). Increasing salinity levels had a deleterious consequence on all growth, physiological, biochemical, and yield components, particularly at 6 dS/m level of salinity. In comparison to controls, the use of nano silicon foliar application is recommended to mitigate the negative effects of salinity by induction of some physiological and biochemical changes, including increased chlorophyll, enzymatic and non-enzymatic antioxidants and decreased Na+ concentrations as well as improved seed weight of plants by twice times. This study suggests spraying common bean plants with Nano silicon, nano biofertilizer or nano seaweed.

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الإستجابات الفسيولوجية لنبات الفاصوليا لبعض المحفزات الحيوية النانوية تحت ظروف الإجهاد الملحي

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تهدف هذه الدراسة لتقييم بعض التغيرات الفسيولوجية والبيوكيميائية في نباتات الفاصوليا نتيجة الرش الورقي لبعض المحفزات النانوية (السيليكون، البولي أمين، الأعشاب البحرية والسماد الحيوي) تحت ظروف الإجهاد الملحي.
أجريت تجارب أصص في الصوبة الزراعية بالمزرعة التجريبية بكلية الزراعة جامعة المنوفية، شبين الكوم، مصر خلال موسمي الصيف 2019 و 2020. أدت معاملة الإجهاد الملحي (6 dS/m) إلى إنخفاض معنوي في النمو، الخصائص الفسيولوجية، صبغات التمثيل الضوئي، القياسات الكيميائية والمحصول. كما أدى إستخدام المحفزات النانوية إلى تقليل الآثار الضارة للملوحة على جميع القياسات المذكورة سابقاً لنباتات الفاصوليا، وكان أفضل تأثير هو محفز النانو سيليكون متبوعاً بالسماد الحيوي النانوي على جميع القياسات، وقد وجد أنه كلما زاد مستوى الملوحة إنخفض وزن البذرة (جم/نبات) معنوياً بحوالي 40% عند مستوى ملوحة 6 dS/m. مقارنة بالكنترول أدى إستخدام النانو سيليكون إلى زيادة معنوية في المساحة الورقية، المحتوى المائي النسبي، تركيز البرولين ووزن البذور بحوالي 84، 53، 49، 91% على التوالي عند مستوى ملوحة 6 dS/m. للتخفيف من الآثار السلبية للملوحة وتحسين الإنتاج، تقترح هذه الدراسة رش نباتات الفاصوليا بالنانو سيليكون متبوعاً بالسماد الحيوي النانوي ثم مستخلص الأعشاب البحرية النانوية.