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Use of Silicon Nanoparticles as a Seed-Priming Solution for increasing the Germination and Growth Parameters of Faba Bean (*Vicia faba* L.) Seedling under Salinity Stress

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ABSTRACT

The use of saline water in agriculture is increasing these decades due to the scarcity of fresh water. The use of silicon nanoparticles is a new approach that can alleviate the adverse effect of saline water on plant growth. The current study was carried out to evaluate the impact of silicon nanoparticles (BSNPs) under salinity stress on seed germination and seedling growth parameters of faba bean (*Vicia Faba* L.) seedling. The research investigated the interaction between six BSNPs (0, 1500, 3000, 4500, 6000, and 7500 mgL^{-1}) and five salinity levels (freshwater: seawater) (0.70, 1.1, 1.6, 2.1, and 3.1 dSm^{-1}). The results revealed a significant decrease in the germination percentage (GP) with increasing salinity levels for the seeds primed in freshwater than that primed in fresh water and BSNPs. Salinity adversely affected the length of the faba bean radicle for seeds priming in freshwater or in fresh water and BSNPs. This was more noticeable for the seeds primed in freshwater than the seeds primed in BSNPs at high salinity levels. The priming in BSNPs significantly reduced the radius of the root seedlings and the priming in 7500 mgL^{-1} gave the lowest value for the radius of the radicle. The Increase in salinity levels decreased the total biomass of faba bean for seeds primed in fresh water, contrary to seeds primed in BSNPs. Vigor and salt tolerance indices were significantly affected by levels of salinity, BSNP treatments, and interactions. The study concluded that BSNPs are alleviating material that can used to enhance germination and growth parameters of plants under salinity stress. Moreover, these results highlighted the positive effects of silicon nanoparticles synthesized from rice straw on reducing the harmful effects of high levels of salinity.

INTRODUCTION

Salinity stress is a sever inhibitor for plant growth. Salinity limits plant growth due to nutrients imbalance, osmotic stress and oxidative stress (Balasubramaniam et al., 2023). The salt accumulation in the soil decreases the ability of plants to extract water, so physiological drought on plants will take place, which is the major stress affecting plant growth. Application of silicon is a promising method that improves plant resistant to salinity stress. Silicon treatment has improved the salinity tolerance for many plants as wheat, rice, sorghum, cucumber and maize (Ahmad et al., 1992, Zhu et al., 2004, Rohanipoor et al., 2013, Yin et al., 2013 and Flam-Shepherd et al., 2018).

Plant productivity is adversely affected by salinity stress. (Around 800 million hectares are affected by salinity or sodicity (FAO, 2005). Salinity is one of the major abiotic stresses which adversely affect crop productivity and quality. The problem of soil salinity in semi-and arid areas is further increasing because of high temperature, high evapotranspiration, low precipitation, poor water quality in irrigation and poor drainage.

A grain legume is an important source of protein and carbohydrates. Faba bean is one of the main winter grain legume food crops in Egypt. Faba bean has highly protein and nutritive content where the proteins content can reach up to 24%. Also, faba bean has an important role as a part of nitrogen fixation process. The cultivation area of beans was decreased around the world. Faba bean is a highly sensitive-moderate to salinity and drought than some other seed legumes (McDonald and Paulsen., 1997; Amede and Schubert., 2003).

Silicon is the second component in the soil which is formed 60-70% of the soil mass (Richmond and Sussman, 2003). Many studies have revealed that the role of silicon to alleviate the abiotic stress as salinity, water stress, metal toxicity and temperature stress (Tripathi et al., 2012a; Tripathi et al., 2012b; Soundararajan et al., 2014; Deshmukh et al., 2020a). Silicon is a non-essential but beneficial element, increases growth through improving tolerance against salinity, insects, water logging, metal toxicity and nutrient deficiency or toxicity. The useful effects of Si in increasing the tolerance of the plant to the biotic and abiotic stresses are proved in many studies (Chen et al., 2014, Debona et al., 2017 and Kube et al., 2021).

The application of nanotechnology in agriculture is a promising and a powerful tool to alter crop production, and can changed plant production through different aspects as enhanced the nutrient use efficiency, increased plant tolerance, and regulated germination and growth of plant (Rastogi et al., 2019). The effects of nanoparticles on plants depend on many factors as the size, shape, chemical and physical properties of nanoparticle and method of application of it (Rastogi et al., 2017). Several studies reported that chemically synthesized of nano-SiO_2 improved seed germination and growth characteristics by reducing electrolyte leakage. Also, application of nano-SiO_2 improved seed germination and seedlings parameters such as fresh and dry weight (Siddiqui and Al-Whaibi 2014), decreased chlorophyll degradation, increased transpiration rate , and water use efficiency (Hussain et al., 2021 and Rahimi et al., 2021).

Therefore, the main object of present study was to study the effect of seed priming in synthesied Bio-Silica Nanoparticles (BSNPs) solution on seed germination and seedling growth parameters of faba bean under salinity stress.

MATERIALS AND METHODS

1. Chemicals

The rice straw was obtained from rice mills in Egypt. Hydrochloric acid was purchased as an analytical reagent from El Gomhouria Company, Egypt. MilliQ water was used during the experiment.

2. Synthesis of Bio-Silica Nanoparticles (BSNPs):

Figure (1) shows a schematic diagram of BSNPs formation according to (Alshatwi et al, 2015). Rice straw (RS) contains cellulose, silica, lignin, hemicellulose, and a trace amount of metal ions. RS is pre-treated with hydrochloric acid which eliminates the impurities of metal ions and decomposes cellulose, hemicellulose and lignin in rice straw. The acid-treated waste is calcined which removes the organic matter and produces silica nanoparticles of high purity and amorphous.

The synthesis of BSNPs is shown in figure (2). First the required rice straw was mixed with 1 N HCl under magnetic stirring; then transferred the mixtures to the autoclave under pressurized conditions (15 lbs). Next, acid-digested rice straw were washed with deionized (DI) water three times to remove HCl. Then, the sample was dried at 85 °C for 5 hours in an oven. After that, the samples were calcined at 700 °C for 1 hour using a muffle furnace. Finally, the color of brown residue changed to white that indicated silica formation.

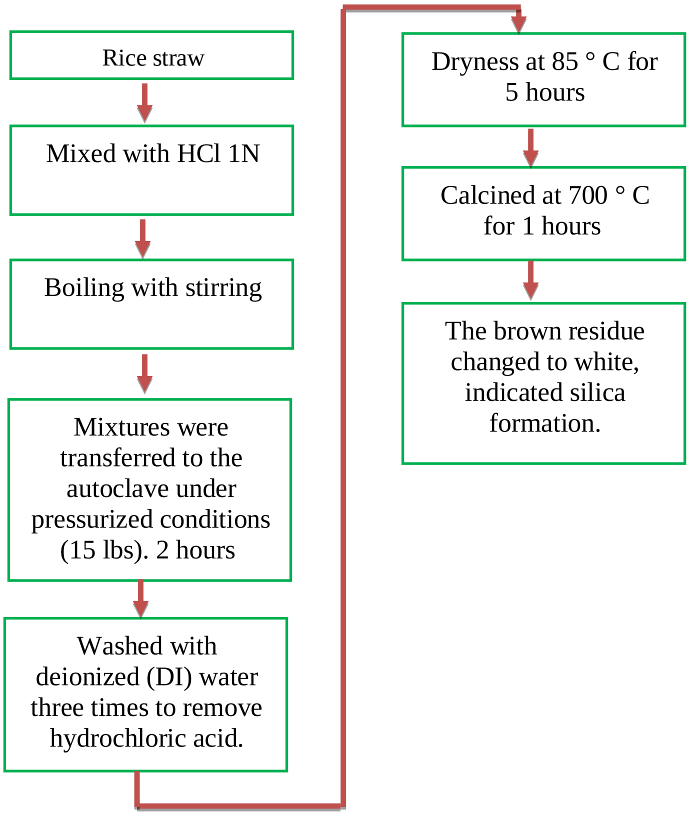

Figure 1: Flow chart of the procedure used to produce silica powders from rice straw.

Characterization of the BSNPs

The crystallization of the samples was characterized using x-ray diffraction (XRD) powder (Model - JEOL). Silica samples were milled with KBr to prepare pellets for Fourier Transform Infrared (FTIR) characterization, which was achieved on a Perkin Elmer spectrum one FT-IR spectrophotometer. Dynamic light scattering (DLS) analysis of samples prepared in aqueous solution was performed using a Zetasizer Nano ZS-90 Analyzer (Malvern, UK). Average volume was calculated using the software based on density and volume distributions and measured numbers. The obtained silica powders were dispersed in absolute ethanol and ultrasound before Transmitting Electron Microscope (TEM) characterization. The shapes, sizes, and elemental compositions of the samples were examined using a JEOL (TEM) at an accelerator voltage of 200 kV.

3. Experimental layout:

Faba bean seeds (*Vicia Faba* L.) were washed with distilled water prior to use. The priming solution were six BSNPs treatments (0, 1500, 3000, 4500, 6000 and 7500 mgL^{-1}) and five salinity levels (fresh water: sea water) (0.70, 1.1, 1.6, 2.1 and 3.1 dSm^{-1}). The seeds were soaked in the previous solutions for 24 h at 28 C° in three replicates for each treatment. Then, the germination and seedling characteristics were measured daily up to 9 days by taken three seeds from each treatment.

3.1. Radicle Length, radius and surface area of radicle

The radicle length, radius and surface area were determined according to (Mahdy et al, 2020). The plant Fresh and dry weights were measured and recorded. The germination percentage was calculated according to (Jones, 2011) using the following equation:

Germination Percentage (GP),% = (number of normally germinated seeds)/(total number of seeds)x100

3.2 Seed water content:

The seed water content (WC) was calculated using the following equation:

$$WC, \% = \frac{(\text{Fresh Weights (g)} - \text{Dry Weights (g)})}{(\text{Fresh Weights (g)})} x\ 100,$$

(Gairrola et al, 2011).

3.3 Germination index (GI):

Germination index was calculated as follows:

IG, unit less $= \frac{\sum d_i\ x\ N_i}{S}$. (Li, 2008)

Where: d_i the days from the start of the experiment, N_i germinated seeds number, and S is number of seeds sown.

3.4 Mean Germination Time (MGT):

MGT was calculated using the following equation:

GTM, day $= \sum n_i .d_i / \sum n_i$ Where: n_i germinated seeds number and d_i the days from the start of the experiment, (Ellis and Roberts, 1981)

3.5 Radicle Length change (RL.):

RLC was calculated using:

$$LRC, \% = \frac{(RL_{S0} - RL_{Sx})}{(RL_{S0})} x\ 100,$$

Where: RL_{S0} is the length of radicle at control; RL_{Sx} is the length of radicle at salt concentration

3.6 Salinity Tolerance and vigor indices:

Salinity tolerance index is the ratio between total fresh weights for stressed plant to controlled plants.

Salinity tolerance index (%)=

$$\frac{(\text{Total Fresh Weight at } S_{salinity})}{(\text{Total Fresh Weight at } S_{control})} x\ 100.$$

Fathi and Gaafar, (2015)

The vigor index (VI) of faba bean seedling calculated as follows:

$$IV = \frac{(\text{final germination percentage} \times \text{seedling height,cm})}{100}$$

Elouaer and Hannachi, (2012)

3.7. Statistical analysis

The experiment design was Complete Randomized Design (CRD) using three replicates in each treatment. The results of the experiment were statistically analysis using Costat software package 6.311 for variance analysis, statistically significance was applied using two ways ANOVA at the ($p \leq 0.05$) level. The significant differences test among three treatments was done at separated probability by least significance difference test ($\rho \leq 0.01$). The Means values were done for three replications.

RESULTS

1. Biogenic of Si nanoparticles characterization

SEM, EDX, XRD, TEM and FTIR analyses of BSNPs are shown in (Figure 2). Scanning Electron Microscopy (SEM), transmission electron microscopy (TEM) images of the BSNPs samples clearly showed different sizes and different shapes indicating that the prepared BSNPs particles possessed an irregular and non-uniform structure (Figure 2a) (Sun et al., 2014). On the other hand, BSNPs confirmed that the representative dimension of single particle size is in the range 1- 28 nm (nanostructure) using Bettersizer 2600(Wet) (Figure 2f). The EDX analysis revealed that the elements carbon, oxygen and silicon represent 97.54% of the total chemical composition (Figure 2c).

Surface characterization of BSNPs using FTIR spectroscopy contributes to identify the functional groups present in its structure (Ngah & Hanafiah, 2008). (Figure 2d) shows FTIR spectra of BSNPs. Spectral bands showed the appearance of intense bands at 3922.38, 3898.27, 3885.73, 3880.91 and 3471.02 cm^{-1} ascribed to the vibrational stretching of the O–H bond (Stuart 2004; Han et al., 2010; Gonçalves et al., 2011, Feng et al., 2011). Spectral peak at 2350.34 cm^{-1} referred to vibrational stretching of C–O bond of alkane groups (Barbosa, 2007) which confirmed modification silicon to BSNPs. The spectral strong bands observed at 1873.91cm^{-1} may be attributed to the vibrational stretching of C=O bond. The peak of 1641.48 cm^{-1} could be referred to the vibrational stretching of C-H bond of amide (Han et al., 2010). The band at 1094.64 cm^{-1} attributed to corresponds to Si-O-Si bonds. (Guo et al., 2008). The peaks observed at 462.82 cm^{-1} correspond to stretching vibration of Si-O-Si group (Sekhar et al. 2009).

The XRD pattern of BSNPs shows sharper peaks which indicate better crystallinity are displayed in (Figure 2e). The results of XRD analysis indicate presence of Silicon Oxide (47.55 %), Copper Iron Phosphate (25.66%), Chromium Phosphate (23.03 %), and Carbonyl Cobalt (3.76 %). The results of XRD analysis which obtained in the present investigation are in good agreement with the reported results (Bouyer et al., 2000).

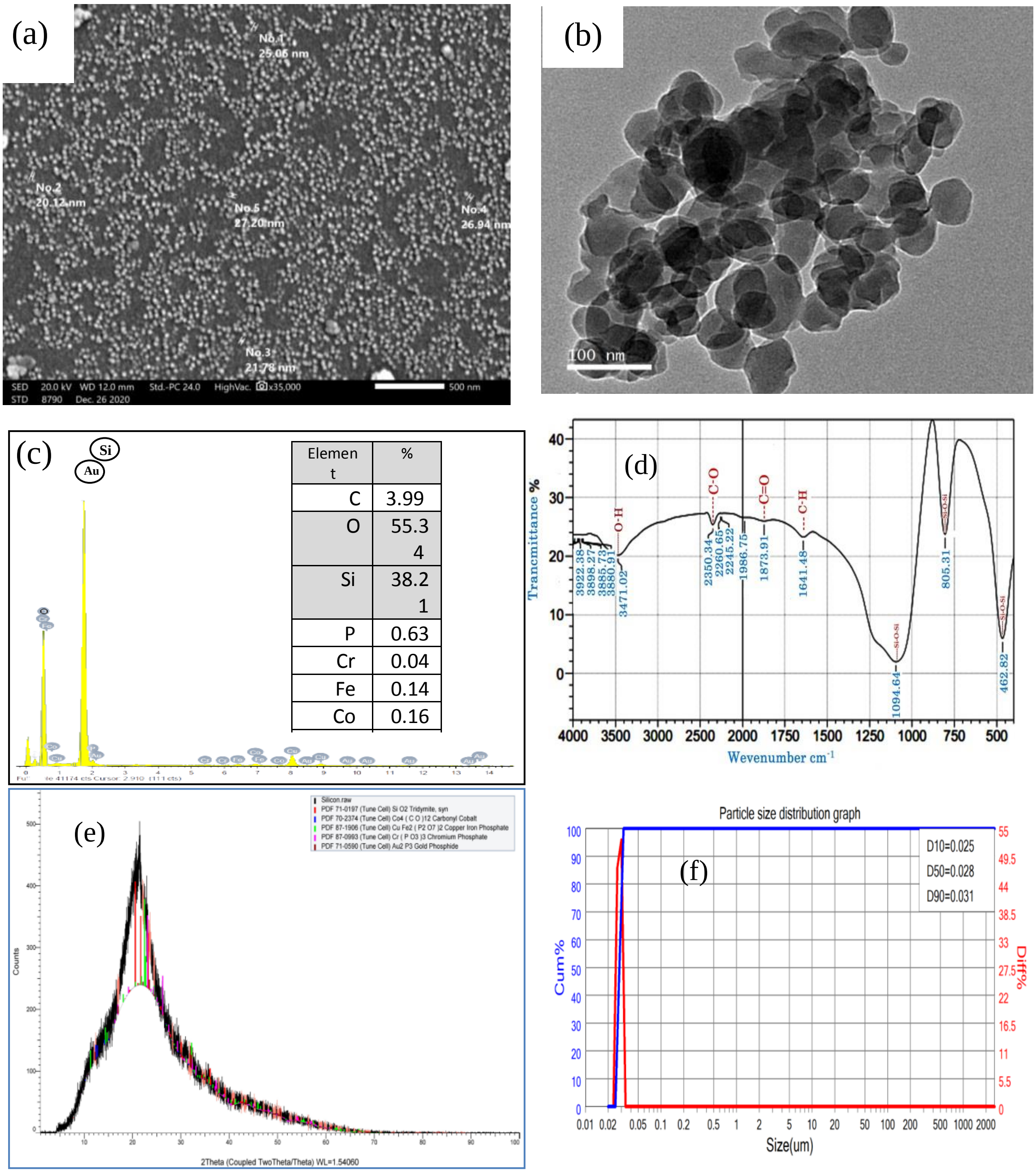

Fig. 2: Scanning electron microscopy (SEM) image (a), Transmission electron microscopy (TEM) (b), energy dispersive X-ray (EDX) (c), FTIR spectrum (d) , X-Ray Diffraction (XRD) (e) and Particle Size Analysis (f) of prepared BSNPs using 700 °C calcination temperature.

2. The water content of faba bean seeds

The increasing in salinity levels declined the water content of seeds at all treatments (Table 1) However, the priming in BSNPs increased the water content in seeds compared the control.

3. Germination percentage (GP)

The germination percentage is a key parameter in plant life cycle and it is highly sensitive to salinity stress. Results showed that increasing in salinity levels from 0.7 to 3.1 dSm^{-1} led to a decreasing in germination percentage (Table 1). This decreasing was more noticeable in unprimed seeds than primed seeds at all salinity levels. The reduction in germination percent declined to 10% in the control at 3.1 dSm^{-1} in comparison to the primed seeds.

4. Germination Index

The index of germination decreased significantly ($\rho \leq 0.01$) when the salt concentration was increased (Table 1). However, this decrease was more obvious for primed seeds when compared to un-primed ones. For example, at a salinity level of 3.1 dSm^{-1} primed seeds in BSNPs concentrations significantly increased ($\rho \leq 0.01$) seed germination index values from 1.20 to 1.80, 2.40, 3, 3 and 2.82 at 0, 1500, 3000, 4500, 6000 and 7500 mgL^{-1} BSNPs, respectively (Table 1). ANOVA also clearly indicated that salt concentrations and priming in BSNPs significantly ($\rho \leq 0.01$) affected the germination index (Table2).

5. Mean germination time (MGT)

The mean germination time is increased significantly ($\rho \leq 0.01$) with the increase of salinity levels (Table 2). The MGT for BSNPs primed seeds is less than unprimed seeds. However, at a salinity level of 3.1 dSm^{-1}, seed primed in BSNPs increased significantly ($\rho \leq 0.05$) the mean germination time from 0.67 at 0 mgL^{-1} BSNPs to 1.67, 1.67, 1.67, 1.67 and 1.50 days at 1500, 3000, 4500, 6000 and 7500 mgL^{-1} BSNPs respectively. ANOVA showed that BSNPs priming is significantly ($\rho \leq 0.05$) affected the MGT (Table 1). These results are consistent with those of (Solanti 2012, Mushtaq et al 2017; Mahdy et al., 2020).

Table 1: Effect of priming in BSNPs nanoparticles solution and salinity levels on water content, germination percentage, germination Index, and mean germination time of faba bean seed.

	BSNPs, Mg/L						
Salinity, dS/m	0	1500	3000	4500	6000	7500	Mean
			Water Content, %				
0.7	82.62	86.24	84.86	87.26	87.46	87.73	86.03
1.1	81.68	83.15	83.72	85.78	86.41	87.08	84.64
1.6	80.67	81.13	82.70	83.15	84.13	85.92	82.95
2.1	79.17	80.52	81.19	81.72	76.13	75.10	78.97
3.1	77.31	79.86	80.96	80.07	73.64	63.28	75.85
Mean	80.29	82.18	82.69	83.60	81.55	79.82	81.69
			Germination percentage, %				
0.7	100	100	100	100	100	100	100
1.1	85.77	87.11	93.33	96.67	98.66	99.33	93
1.6	81.67	84.22	91.55	96.33	97	98.67	92
2.1	53.33	75	86.67	88.89	91.21	98	82
3.1	40.00	71	80	85	86.66	90	76
Mean	72.15	83.60	90.31	93.38	94.71	97.20	88.56
			Index of germination				
0.7	3.00	3.00	3.00	3.00	3.00	3.00	3
1.1	3.00	2.40	3.00	3.00	3.00	3.00	3
1.6	1.80	3.00	3.00	3.00	2.40	2.88	3
2.1	1.20	3.00	3.00	2.40	3.00	2.94	3
3.1	1.20	1.80	2.40	3.00	3.00	2.82	2
Mean	2.04	2.64	2.88	2.88	2.88	2.93	2.71
			Mean germination time, day				
0.7	1.67	1.67	1.67	1.67	1.67	1.67	2
1.1	1.67	1.33	1.67	1.67	1.67	1.67	2
1.6	1.00	1.67	1.67	1.67	1.67	1.60	2
2.1	0.67	1.67	1.67	1.33	1.67	1.63	1
3.1	0.67	1.67	1.67	1.67	1.67	1.50	1
Mean	1.14	1.60	1.67	1.60	1.67	1.61	1.55

Table 2: ANOVA analysis for the effect of priming in BSNPs, salinity levels and their interactions on the germination percentage and seedling growth parameters of faba bean.

	BSNPs, Mg/L^{-1}						
Salinity, dS/m	0	1500	3000	4500	6000	7500	Mean
Radicle Length, cm							
0.7	12.90	13.29	14.13	13.67	13.38	11.17	**13.09**
1.1	12.38	13.00	13.21	12.75	12.00	9.58	12.15
1.6	11.13	12.17	13.13	11.63	10.02	9.50	11.26
2.1	9.70	11.75	13.00	9.25	8.25	8.00	9.99
3.1	7.50	10.50	12.79	8.00	7.50	7.13	8.90
Mean	10.72	12.14	13.25	11.06	10.23	9.08	11.08
Radicle radius, mm							
0.7	1.46	1.44	1.39	1.38	1.37	1.31	1.39
1.1	1.58	1.48	1.43	1.41	1.40	1.37	1.44
1.6	1.59	1.49	1.44	1.43	1.41	1.39	1.46
2.1	1.64	1.51	1.46	1.44	1.42	1.40	1.48
3.1	1.67	1.66	1.48	1.47	1.43	1.43	1.52
Mean	1.59	1.52	1.44	1.43	1.41	1.38	1.46
Radicle surface area, cm^2							
0.7	4.96	9.76	10.15	10.80	11.08	11.59	12.12
1.1	2.87	9.36	9.85	10.43	10.89	10.91	11.10
1.6	2.65	8.97	9.67	9.84	10.18	10.58	10.88
2.1	2.28	8.24	8.89	9.19	9.73	10.31	10.50
3.1	2.23	7.81	8.11	8.63	9.41	9.46	9.42
Mean	3.00	8.83	9.34	9.78	10.26	10.57	10.81

6. Early seedling growth parameters

6.1 Radicle length changes

Salt stress adversely affected radicle length of faba bean seedlings produced from seed primed and unprimed in BSNPs solution (Figure 3). But this effect was widely obvious in the root length of the seedlings obtained from the control treatment (unprimed seeds in BSNPs) than unprimed seeds, and the maximum reduction in root length was observed at 3.1 dSm^{-1} salt level (Table 3).

Table 3: Effect of priming in BSNPs nanoparticles concentrations and salinity on radicle length, radicle radius, and radicle surface area of faba bean seeds.

	BSNPs, Mg/L^{-1}						
Salinity, dS/m	0	1500	3000	4500	6000	7500	Mean
Radicle Length, cm							
0.7	12.90	13.29	14.13	13.67	13.38	11.17	13.09
1.1	12.38	13.00	13.21	12.75	12.00	9.58	12.15
1.6	11.13	12.17	13.13	11.63	10.02	9.50	11.26
2.1	9.70	11.75	13.00	9.25	8.25	8.00	9.99
3.1	7.50	10.50	12.79	8.00	7.50	7.13	8.90
Mean	10.72	12.14	13.25	11.06	10.23	9.08	11.08
Radicle radius, mm							
0.7	1.46	1.44	1.39	1.38	1.37	1.31	1.39
1.1	1.58	1.48	1.43	1.41	1.40	1.37	1.44
1.6	1.59	1.49	1.44	1.43	1.41	1.39	1.46
2.1	1.64	1.51	1.46	1.44	1.42	1.40	1.48
3.1	1.67	1.66	1.48	1.47	1.43	1.43	1.52
Mean	1.59	1.52	1.44	1.43	1.41	1.38	1.46
Radicle surface area, cm^2							
0.7	4.96	9.76	10.15	10.80	11.08	11.59	12.12
1.1	2.87	9.36	9.85	10.43	10.89	10.91	11.10
1.6	2.65	8.97	9.67	9.84	10.18	10.58	10.88
2.1	2.28	8.24	8.89	9.19	9.73	10.31	10.50
3.1	2.23	7.81	8.11	8.63	9.41	9.46	9.42
Mean	3.00	8.83	9.34	9.78	10.26	10.57	10.81

Table 4: ANOVA analysis for the effect of priming in (BSNPs), salinity levels and their interactions on the radical radius, radical surface area, radical length and seedling growth parameters for faba bean after time of germination.

	F-Values						
Source of variance	**RL**	**RR**	**RSA**	**TFW**	**TDW**	**STI**	**VI**
$LSD_{0.05}$ (Salinity)	0.293	0.360	0.529	0.630	0.570	6.47	0.598
$LSD_{0.05}$ (BSNPs)	0.32	0.394	0.580	0.690	0.625	7.087	0.655
$LSD_{0.05}$ (Salinity x BSNPs)	1.23	1.528	2.245	2.675	2.420	27.451	2.540
Salinity	***	***	***	***	***	***	***
BSNPs	***	ns	ns	**	***	***	ns
(Salinity x BSNPs)	***	ns	***	***	***	***	***

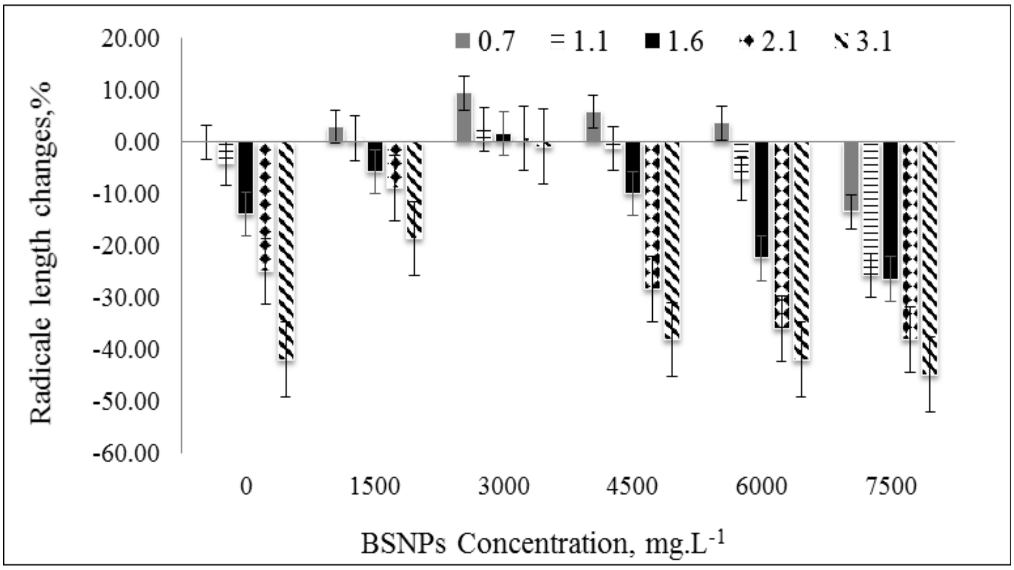

Figure 3: Effect of Salinity Stress on radicle length changes of Faba bean seedligs. The standard error of the mean of three replicated was represented as error bars.

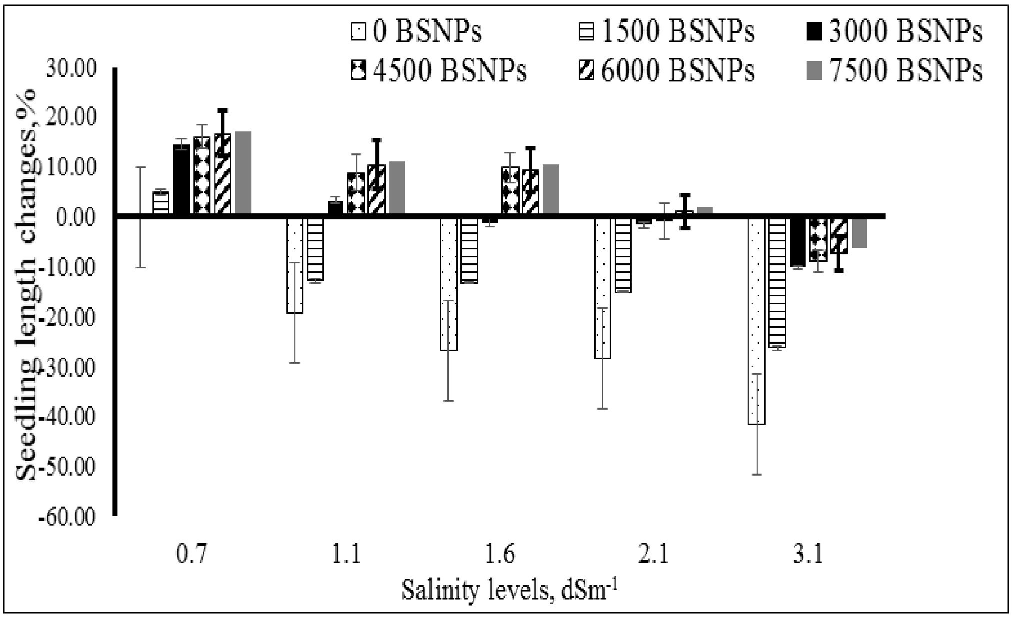

Figure 4: Effect of the priming in BSNPs on seedlings length changes (%) of fabe bean seedlings under different salinity levels. The standard error of the mean of three replicated was represented as error bars.

6.2. Radicle radius and radicle surface area

(Table 3) showed the radicle radius for primed seeds in BSNPs or unprimed of fabe bean seedling under salinity levels. The ANOVA showed that the RR was significantly affected by salinity levels (Table 4).

The Radicle surface area of fabe bean seeds for unprimed seeds was decreased with salinity stress. In contrast to primed seeds in BSNPs which increased with increasing in BSNPs concentration (Table 3). The interaction between salinity and the priming in BSNPs was significantly affected the RSA (Table 4).

6.3. Total fresh and dry weights

(Figure 5 a, b). displayed the total fresh and dry weights of faba bean under salinity levels for primed and unprimed seeds. Increase in salinity levels for unprimed seeds decreases both shoot and dry weights. The highest salinity levels at 3.1 dS/m^{-1} reduced the fresh weight from 5 gm. in control to 3 gm., also the dry weights decreased from 0.83 gm. for the control to 0.62 gm. at 3.1 dS/m^{-1}.

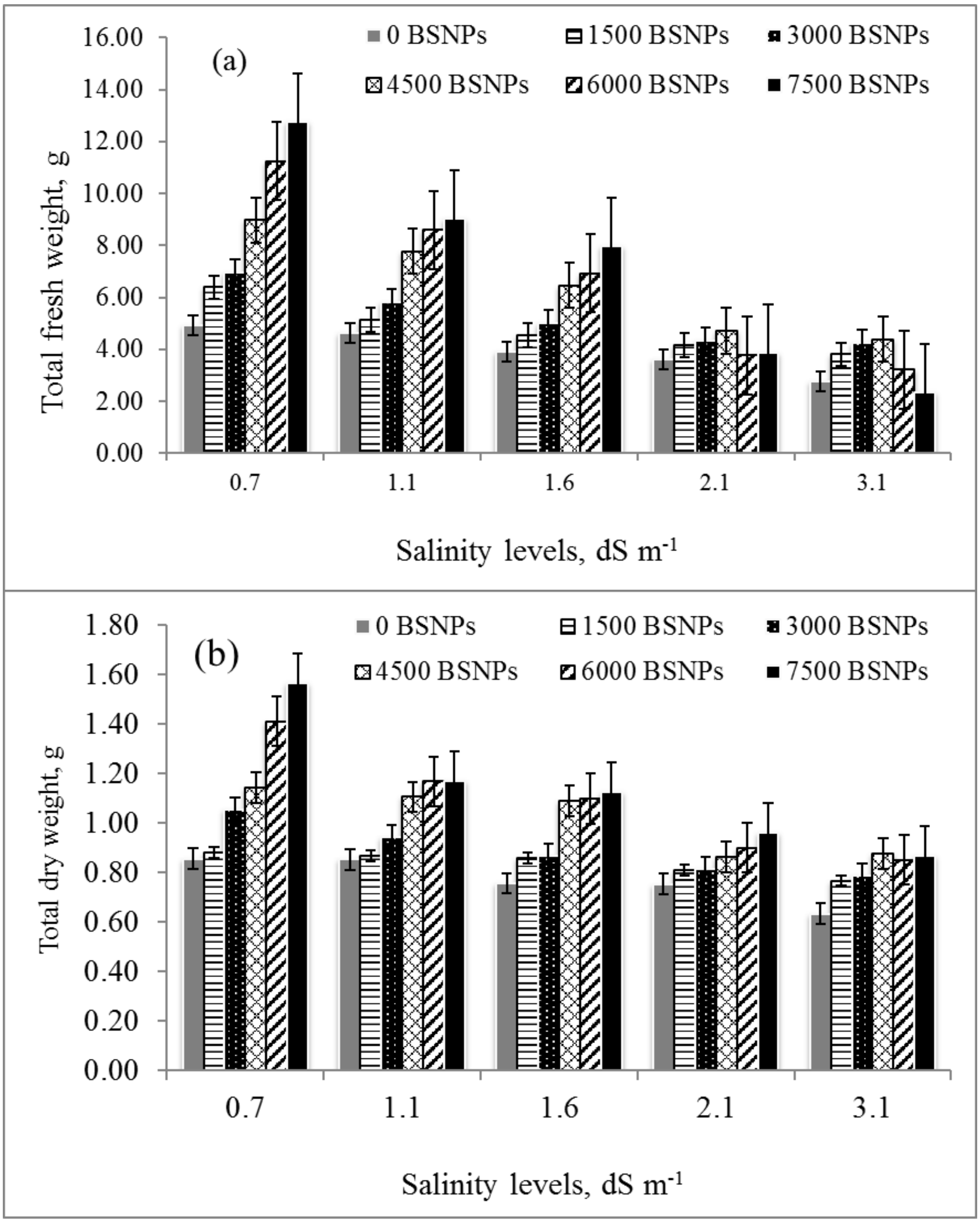

Figure 5: Effect of the priming in (BSNPs) on total fresh and dry weights of faba bean under different salinity levels. The standard error of the mean of three replicated was represented as error bars

6.4. Salt tolerance (STI) and (VI) vigor indices

(Figure 6a) displayed the salt tolerance index of faba bean under salinity levels for primed and unprimed seeds. Increase in salinity levels for unprimed seeds decreases STI. The highest salt tolerance was observed in the control then reduced with increasing in salt concentration until reached the lowest value in 3.1 dS^{-1}.

(Figure 6b) showed vigor index of faba bean under salinity levels for primed and unprimed seeds. There was a decreasing in VI with increasing in salinity levels in unprimed seeds except EC 2.1 dSm^{-1}. This decrease was from 16.98 at 0.70 dS/m to 2.35 at 3.1 dSm^{-1}. In contrast, primed seeds in BSNPs showed an increase of VI with different salinity levels (Figure 6b). The ANOVA variance of analysis results showed a highly significant ($\rho \leq 0.01$) between means in salinity levels, and the interaction between it and BSNPs on VI (Table 4).

At salinity level of 0.70 dSm^{-1}, the increase of VI values was 17.89, 18.77, 20.50, 20.75, 20.88 and 20.92 at 0, 1500, 3000, 4500, 6000 and 7500 mgL^{-1} for primed seeds, respectively (Figure 6b). Also the increase of vigor index values was 3.80, 6.70, and 6.92 at 0, 1500, and 3000 mgL^{-1} at salinity level of 3.1 dSm^{-1}, respectively (Figure 6b). These results were in a good agreement with the results of (Farooq et al. 2005).

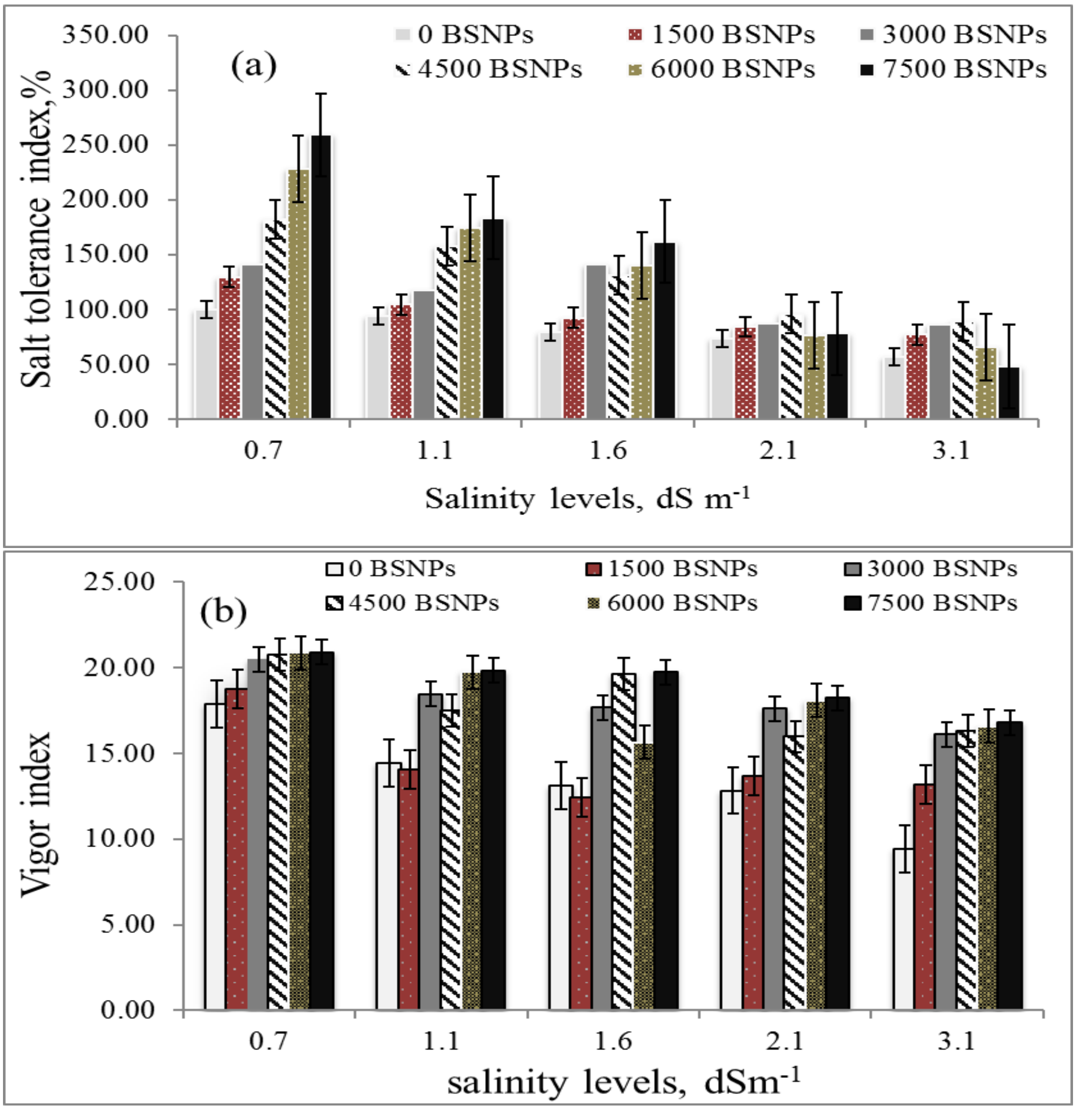

Figure 6: Effect of the priming in (BSNPs) on vigor indices of faba bean seedlings under salinity levels. The standard error of the mean of three replicated was represented as error bars.

DISCUSSION

1. The water content of faba bean seeds

The results indicated that water content decreased due to increase in salinity levels and lowered both water potential and the availability of water, then decreased the water content in seeds (Munns 2005; Panuccio et al. 2014; Sozharajan and Natarjan 2014) on contrary finding of (Tsegay and Gebreslassie 2014) where water content was increased with increasing of salinity.

On the contrary, at all salinity levels, priming of seeds in BSNPs solutions with different concentrations significantly ($\rho \leq 0.05$) increased the water uptake of faba bean seeds, and the highest significant water content was observed at BSNPs concentrations of 3000 mgL^{-1} and the increase in water content was non-significant at higher BSNPs concentrations in comparison with 3000 mgL^{-1} BSNPs .

The seed coat plays a crucial role in regulating the penetration of water into seeds. According to the findings presented in (Table 1), it is evident that as salt levels rise across various priming treatments, there is a noteworthy decrease in the percentage of water uptake in faba bean plants. Elevated salt concentrations within the root zone lead to a reduction in water potential, subsequently triggering osmotic consequences and ultimately resulting in a physiological drought condition. (Kaya et al., 2006). This observation aligns with the finding by (Moaveni, 2011, Hasegawa et al., 2000) However, it contradicts the outcomes reported of (Yan, M. 2015).) In contrast, contrary results were presented by researchers who reported an increase in the water content of *Lathyrus sativus* and *Pisum sativum* seeds as the salt concentration increased. Additionally, when seeds were subjected to priming with nanosilicon of varying ratios, a substantial enhancement in water uptake was observed, with the most significant improvement occurring at a concentration of 4500 mg^{-1}. This notable increase in water uptake can be attributed to the remarkable water-retention capabilities of nanosilicon particles, which may potentially penetrate plant cells due to their small size (28 nm).

2. Germination percentage (GP)

The results indicated that the priming in BSNPs increased the germination percentage for unprimed seeds in comparison with primed seeds where the priming in BSNPs alleviate salt stress and increase germination percentage of faba bean seeds. These results are also in a close agreement with (Mahdy et al. 2020). The reduction in germination percentage with increasing salinity levels is due to the adversely effect of salt on physiological parameters. (Khan et al. 2002). (Khajeh et al. 2003) reported that the ion specific toxicity of Na and Cl decrease the germination percentage. (Elouaer and Hannachi 2012) stated that priming in BSNPs allowed the metabolic process during germination happen sooner than progress in radicle emergence (Afzal et al. 2008) showed that the germination is increasing in primed seeds because of the metabolism of protein and rapid synthesis of nucleic acid through seed soaking.

3. Radicle length changes

The increased salt concentration ($\rho \leq 0.05$) significantly reduced radicle length because the effect of ion toxicity and osmotic pressure on seedling growth. Moreover, salinity effect can delay absorption of K and P that through seed growth (Ma et al. 2020). In the current study, seeds were primed with different concentrations of BSNPs significantly improved faba bean length exposed to different salt levels.

The growing enhancement observed at 0.70 dSm^{-1} and 3000 mgL^{-1} BSNPs and the values of radicle length at the other BSNPs concentrations were significantly increased. (Jan mohammadi et al. 2015) announced that high enhancement in radicle length caused by seeds priming in BSNPs induced by the changes in tissue pliability. More active seedlings were produced from seeds prepared in BSNPs compared to the control treatment (unprimed in BSNPs). This results in a good agreement with results of (Jan mohammadi 2015) who showed that seed priming in nanosilicon significantly enhanced root lengths of sunflower.

Concerning radicle length changes, Application of different salinity levels had a significant reduction on radicle length of faba bean seedlings in control and BSNPs primed seeds (Figure 3). Moreover, this adversely affect was low in primed seeds in BSNPs in compared with unprimed seeds (Figure 3). The priming of seeds in different concentrations of BSNPs significantly reduced the effect of salinity stress on radicle length compared with the unprimed seeds.

4. Radicle radius (RR) and radicle surface area (RSA)

The radicle radius increased with increasing in salinity levels for unprimed seeds which observed had the highest value at salinity levels 3.1 dSm^{-1}. In contrary the priming in BSNPs significantly decreased the radicle radius for fabe bean seedling. The best reduction in RR found at the highest level of BSNPs, so the priming of faba bean seeds in BSNPs improved the tolerance of seedling to salinity through decreasing the radicle radius. The RSA for the primed seeds is higher than unprimed seeds at 7500 mgL^{-1} level. This was due to improvement the metabolism of nuclei acid and protein in the treatment with BSNPs (Awadallah, 2019).

5. Total fresh and dry weights

These reduction in the increase of salinity levels significantly reduced fresh and dry weights were due to the adversely effect of salinity on growth and physiological parameters (Kapoor, 2015). These results were in a good agreement with (Achakzai,2010 and Anuradha,2014). The effect of priming seeds in BNSPs improved both shoot and dry weights compared to unprimed seeds. BNSPs enhanced fresh weight under salinity stress through regulation plant growth and maintain high photosynthetic rate under salt stress (Yin 2013, Coskun et al., 2016, Zagar et al., 2019).

6. Salt tolerance (STI) and (VI) vigor indices

The effect of priming seeds in BNSPs improved the salt tolerance index compared with the control. The effect of silicon nanoparticles resulted in a significant increase in STI at all salinity levels, but 7500 mgL^{-1} have got the best effect. The BSNPs alleviate the salinity effect and increase salt tolerance through reducing the Na and Cl levels in the root system (Liang, 2003)

The most elevated STI, VI was noticed at 0.7 dSm-1 and the least value of salt tolerance and vigor indices at 3.1 dSm^{-1}.Generally, seed priming of faba bean in different ratios of nanofertilizers significantly ($p < 0.05$) raised the STI and VI at all salt stress concentrations, but the 7500 mgL^{-1} achieved the best soaking treatment. So, the priming in BNSPs produced seedlings having a higher tolerance to salinity conditions than fresh water. This result agreed with the study of (Mahdy et al 2020) reported that nanopriming in water treatment residuals raised STI of cucumber seedlings under salt stress.(Włodarczyk et al,2022) study indicated that nanopriming of ZnO (500ppm), TiO2 (50ppm) and SiO2(25ppm) had given the greatest effect on groundnut seedling vigor index. Also, the study of (Elkhatib et al 2019) investigated that Nano priming in mango peels improved the vigor index of maize seeds. The Small size of the nanoparticles would have easily entered through cracks present on the outer seed surface, reacted with free radicals resulting in enhanced seed vigor (Cumbal, et al., 2005).

CONCLUSION

Seed priming with BSNPs at a concentration of 7500 mgL^{-1} exhibited a positive response in mitigating the adverse effects of salinity stress on the growth parameters of faba bean seedlings. This treatment led to notable enhancements in radicle and plumule length, as well as improvements in the salt tolerance index and vigor of the faba bean seedlings. Furthermore, the application of nanosilicon during priming resulted in a significant increase in the total biomass of the seedlings and the surface area of their radicles, when compared to seedlings treated with fresh water only. However, it's worth noting that radicle radius was observed to decrease in response to nanosilicon priming.

Our findings propose that nutrient seed priming using a BSNPs solution holds significant potential for agricultural purposes. This approach offers a straightforward, cost-effective, and environmentally friendly method that could potentially establish a protective mechanism against oxidative harm and enhance the salt stress tolerance of faba bean plants. This enhancement may be attributed to the effective absorption of nutrients from the nanosilicon solution by the seed coat. However, it is imperative that future research efforts focus on elucidating the physiological and biochemical aspects of salinity stress in various crop species to provide a more comprehensive understanding of this promising technique's applicability.

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الملخص العربي

استخدام جزيئات السليكون النانومترية كمحلول لنقع البذور لزيادة نسبة الإنبات ومعايير نمو بادرات شتلات الفول البلدي تحت الإجهاد الملحى

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يتزايد استخدام المياه المالحة في الزراعة خلال هذه العقود بسبب ندرة المياه العذبة. يعد استخدام جزيئات السيليكون النانوية طريقة جديدة يمكن أن تخفف من التأثير السلبي للمياه المالحة على نمو نبات الفول البلدى. أجريت الدراسة الحالية لتقييم تأثير جزيئات السيليكون النانوية (BSNPs) تحت إجهاد الملوحة على إنبات البذور ومعايير نمو بادرات شتلات الفول البلدي.

تم دراسة التفاعل بين ستة تركيزات من السليكون النانوى (ماء مقطر، ١٥٠٠، ٣٠٠٠، ٤٥٠٠، ٦٠٠٠ و ٧٥٠٠ مليجرام / كيلو جرام) وخمسة مستويات ملوحة (المياه العذبة : مياه البحر) (٠,٧، ١,١، ١,٦، ٢,١، و ٣,١ ديسيسيمنز/سم).

أظهرت النتائج انخفاضا معنويا في نسبة الإنبات (GP) مع زيادة مستويات الملوحة للبذور التي نُقِعتْ بالمياه العذبة مقارنة بتلك التي نُقِعتْ بالمياه العذبة ومحلول السليكون النانوى. كما أثرت الملوحة سلباً على طول جذر نبات الفول البلدي عند نقع البذور في المياه العذبة أو في المياه العذبة ومحلول السليكون النانوى. كان هذا أكثر وضوحاً بالنسبة للبذور المنقوعة بالمياه العذبة مقارنة بالبذور المنقوعة في محلول السليكون النانوى عند مستوى ملوحة عالي. بالإضافة لذلك أدى النقع في محلول السليكون النانوى إلى تقليل نصف قطر جذر الشتلات بشكل كبير وأعطى النقع في تركيز السليكون النانوى ٧٥٠٠ ملجم/ كجم أقل قيمة لنصف قطر الجذر. كما أدت الزيادة في مستويات الملوحة إلى انخفاض الكتلة الحيوية الكلية لنبات الفول البلدي للبذور المنقوعة بالمياه العذبة، على عكس البذور المجهزة بــمحلول السليكون النانوى. أيضاً تأثرت دلائل القوة وتحمل الملح بشكل كبير بمستويات الملوحة ومعاملات محلول السليكون النانوى.

من هنا يتضح أن جسيمات السيليكون النانوية هي مادة تخفف الأثر السلبى للملوحة ويمكن استخدامها لتعزيز نسبة الانبات ومعايير النمو للنباتات تحت ظروف الملوحة.

علاوة على ذلك، أبرزت هذه النتائج تأثيرات إيجابية لجسيمات السيليكون النانوية المصنوعة من قش الأرز على تقليل التأثيرات الضارة لمستويات الملوحة العالية.

الكلمات المفتاحية: معاملات النمو، جسيمات السيليكون النانوية، إجهاد الملوحة، نسبة الانبات.