International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.10 pp 11-17, 2015

Nano Silicon Application Improves Salinity Tolerance of Sweet pepper Plants

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Abstract: Salinity is a major limiting factor for crop growth and productivity especially in arid and semi arid areas. Therefore this study was conducted in order to compare the effect of applying silicon in the standard form versus the nano form on mitigating salinity negative effects on sweet pepper plants (*Capsicum annumn* L.) cv. California Wonder. Seedlings were transplanted in March 2013 and 2014 in North Delta, Egypt and were irrigated with saline water with an EC of 5.47 dS/m. Silicon in two forms (regular 25%) and nano silicon (25%) were supplied through irrigation systems at concentrations of 4.0 and 5.0 cm^3/l for regular silicon and 1.0 and 2.0 cm^3/l for nano silicon. Application took place at 3, 6 and 9 weeks after transplanting.

Data showed that all plant growth aspects such as plant height, number of branches and leaves fresh and dry weights were improved under all silicon treatments compared to non treated plants. Yield parameters followed also the same trend. Among silicon treatments, concentration of 1.0 cm^3/l of nano silicon recorded the highest significant effect in mitigating salinity negative effects. It could be concluded that nano silicon is more effective and efficient in mitigating salinity stress on sweet pepper plants.
Key words: Sweet pepper, Salinity, Nano Silicon, Total chlorophyll, N, P, K and Total Yield.

Introduction:

Nowadays, salinity is became one of the most serious environmental problems that caused great reduction ongrowth and development of plant species. In fact Salinity is one of the major yield limiting factors for crop plants mainly in arid and semiarid regions of the world[1]. In Egypt the problem is aggregated due to overuse of fertilizers and shortage of good irrigation water. Therefore, many trails and approaches have been attempted to mitigate the well-known negative effects of salinity on plant growth and production[2,3,4,5,6]. Among those approaches is the improvement of plant nutritional status via external supplements to ameliorate salinity damages with exogenous application of K^+ in wheat[7], N in *Phaseolus vulgaris*[8] and Ca in snap bean[9]. [10]reported an improvement of tomato crop growth and production under saline conditions as a result of application of nano calcium. Furthermore, some beneficial mineral nutrients have been studied that can counteract adverse effects of salt stress. Silicon, being a beneficial element provides significant benefits to plants at various ionic compositions. Also, [11]proved that nono silicon application can improve seed germination and seedling growth of tomato. Earlier, [12]showed that soyabean plants supplied with silicon had higher salinity tolerance compared to non-supplied plants. Silicon deposition in the tissues help to alleviate water stress by reducing transpiration rate, improve light interception characteristics by keeping the leaf erect, increase resistances to diseases pests and lodging, remediate nutrient imbalances, and there are other documented beneficial effects[13,14,15]. Silicon presence in the cell wall fiber makes the cell wall tough and resistant to pest and pathogens attacks. Naturally, plants contain Si in appreciable concentrations, ranging from 1% to 10% or even higher of the dry matter. This difference of Si levels in different plant species have been attributed to the Si uptake ability of the roots[16,17]. Despite of the prominence of Si as a mineral constituent of plants, Si is not considered as "essential" nutrient, for any terrestrial higher plants except members of the Equisitaceae and is thus not included in the formulation of any of the commonly used nutrient solutions[13]. As the beneficial effect of silicon has been proved as shown above, the application of non silicon can be more effective than the large applied particles which means a more efficient input use. [10]showed that application of nano calcium to saline stress tomato plants had more efficient and effective impact on mitigating the negative effect of salinity compared to the application of chleated calcium. The use of the new science, nanotechnology in agriculture has begun and will continue to have a significant effect in the main areas of breeding new crop varieties, development of new functional materials and smart delivery systems for agrochemicals like herbicides, fertilizers and pesticides, smart systems integration for food processing, packaging and other areas like remediation of herbicide and pesticide residues from plant and soil, effluent water treatment, etc.[18]. Nano-technology can present solution to increasing the value of agricultural products and environmental problems. Nanomaterials because of their tiny size show unique characteristics. They can change physic–chemical properties compared totheir bulk materials, they have a great surface area than bulk materials. Because of these larger surface areas, their solubility and surface reactivity was higher[19]. By manufacturingthe preparation ways of nanomaterials can change their characteristics, for example, the addition of nanoparticlesin liquid changes their chemical, physiological and transport characteristics compared to their base fluids such as enhancement of thermal conductivity[20].

Yet no studies were found on the effect of nano silicon application on the growth and production of sweet pepper plants. In Egypt, sweet pepper is a major vegetable crop for local consumption and export.For these reasons, this study was conducted to compare the effectiveness of applying silicon in the nano or regular forms in reducing the negative effects of salinity on tomato plants growth and production.

Materials and methods:

Seeds of sweet pepper plants (C*apsicum annumn* L.) cv. California Wonder were sown on 15th of January 2013 and 2014 and seedlings were transplanted on the 15th of March in the two seasons of 2013 and 2014 in a sandy soil in a private farm in the area of Wadi El-Natron, Bahaira governorate, Egypt. The soil physical and chemical analysis are shown in tables 1 and 2. Individual transplants were grown at the bottom of ridges 100 cm width at 50 cm apart. Plot area was 1X12= 12 m^2. The drip irrigation system of GR 16 was used and plants were irrigated daily using saline-well water with an EC value 5.47 dS/m and pH of 7.8. The complete chemical analysis of the irrigation water is shown in table (3).

All standard agricultural practices other than experimental treatments were applied according to the recommendations of the ministry of agriculture, Egypt.

Experimental treatments:

After three weeks from transplanting, plants were supplied through the irrigation system with two types of siliconforms namely Nano Silicon (Nano-Si 25%) or regular silicon (Si 25%). Each form was supplied to the plants in two concentrations as follow: Nano-Si : 0.0 (control), 1.0 or 2.0 cm^3/l. Meanwhile Si (25%) was applied as 0.0 (control), 4.0 or 5.0 cm^3/l.

Applications of silicon treatments were at 3, 6 and 9 weeks after transplanting.

Experimental design and statistical analysis:

The treatments were arranged in a complete randomized block design with three replicates and analysis of variance was carried out at probability level of 0.05. Least Significant Difference LSD was calculated to differentiate between the treatments.

Measurements:

After 70 days from transplanting the following measurements were carried out:

Physical measurements: Plant height, number of branches, fresh and dry weights of leaves; total yield (ton/fed.); and average weight of individual fruits (g).

Chemical measurements: Total chlorophyll content (SPAD); total contents of N, P and K (%).

Table (1): Soil physical analysis and soil properties of the experimental farm.

Soil depth (cm^3)	Total sand (%)	Silt (%)	Clay (%)	Texture
0-15	58.0	11.5	30.5	Sandy
30 – 60	57.0	13.0	30.0	Sandy

Table (2): Soil chemical analysis of the experimental farm.

Soil depth (cm^3)	EC (dS/m)	pH	Soluble anions (ppm)			Soluble cations (ppm)			
			CO_3^{--}	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
0-30	4.77	7.7	55.85	31.20	10.50	24	11	10.52	2.18
30-60	4.16	7.4	51.21	22.50	16.10	16.83	6	17.80	0.097

Table (3): Chemical analysis of irrigation water (underground well) of the experimental farm.

Water sample	EC (dS/m)	pH	Soluble anions (ppm)			Soluble cations (ppm)			
			HCO_3^-	Cl^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+
Average	5.47	7.8	2.50	81.08	16.24	25.29	19.43	54.83	0.45

Results:

Data in Table (4) show that plant height was significantly reduced under salinity treatment. Meanwhile all silicon treatments mitigated these negative effects and plant height was improved with superior effects recorded with Nano-Si treatments which were not significantly different between each other. Although Si treatments significantly improved plant height under salinity conditions, they were significantly lower in their effects compared to Nano-Si treatments. Similar trends were observed in the number of branches where all silicon treatments improved this parameter compared to the untreated plants. The Nano-Si treated plants showed the highest mitigated effects compared to Si treatments. The effectiveness of each Si treatment was clear in leaves fresh weight (Table 4). With significant differences among all treatments, Nano-Si treatment of 1 cm^3/l showed the highest effectiveness in mitigating salinity effect on that parameter followed by Nano-Si 2.0 cm^3/l then Si 4.0 cm^3/l and finally Si 5.0 cm^3/l treatment. All silicon treatments showed a significant improvement in leaves fresh weight compared to untreated plants. Dry weight of the leaves showed also a similar trend that all silicon treatments improved that parameter compared to untreated plants grown under saline conditions. However Nano-Si treated plants showed higher significant positive responses compared to regular silicon supplied plants with superiority effect for 1 cm^3/l treatment.

Fruit yield data are shown in Table (5). Average fruit weight of individual fruits was also improved by all silicon treatments compared to untreated plants grown under salinity conditions. The lower concentration of Nano-Si had the highest significant mitigating effect regarding this parameter compared to all other silicon treatments. There was no significant difference between the highest applied concentration of Nano-Si (2 cm^3/l) and the lowest concentration of regular silicon (4 cm^3/l) treatments. Also there was no significant difference between the two concentration treatments of regular silicon. Total fruit yield (Table 5) showed also an improvement as a result of all silicon treatments compared to untreated plants grown under saline conditions. The Nano-Si treatment of 1.0 cm^3/l concentration showed the highest significant mitigating effects on total yield of sweet pepper plants compared to all other silicon treatments. There was no significant difference between the two concentrations of regular silicon treatments.

Chemical analysis data as shown in Table (6) showed that all silicon treated plants showed an improvement in total chlorophyll content compared to control plants grown under salinity conditions. However, only the lowest concentration of Nano-Si treatment that was significantly higher than all other silicon treatments. Nitrogen total content showed also an improvement as a result of all silicon treatments compared to control plants. In addition the only significant difference among silicon treatments was between the lowest Nano-Si treatment and the rest of silicon treatments. Similar trend was observed also in phosphorus total content where all silicon treatments improved that content compared to control treatment. Among silicon treatments, only the highest concentration of regular silicon treatment showed a significant difference compared to other silicon treatments. Potassium total content followed the same observed trend of improvement in all parameters as a result of silicon treatments. There was a significant differences among the treatments with superiority to the lowest concentration of Nano-Si treatment.

Table (4): Effect of different silicon treatments on plant height, leaf fresh and dry weights, and number of branches of sweet pepper plants.

Treatments	2013 Season				2014 Season			
	Plant height (cm)	Leaves fresh weight (g)	Leaves dry weight (g)	No. of branches / plant	Plant height (cm)	Leaves fresh weight (g)	Leaves dry weight (g)	No. of branches / plant
Control	30.45	61.45	14.67	4.32	28.64	59.34	12.40	4.11
Nano Si (25%) 1 cm / Lit.	46.32	98.28	26.49	7.86	44.51	96.50	23.69	7.68
Nano Si (25%) 2 cm / Lit.	44.91	81.19	23.51	7.02	43.27	80.73	21.38	6.93
Si (25%) 4 cm / Lit.	40.23	73.61	19.92	6.57	39.34	71.02	18.43	6.48
Si (25%) 5 cm / Lit.	38.21	69.37	18.23	6.01	35.45	67.47	15.57	5.98
L.S.D. at 5 %	2.09	3.01	1.93	0.92	1.91	1.79	1.57	0.71

Table (5): Effect of different silicon treatments on individual fruit weight and total fruit yield sweet pepper plants.

Treatments	2013 Season		2014 Season	
	Fruit weight (g)	Total Yield ton / fed.	Fruit weight (g)	Total Yield ton / fed.
Control	62.23	5.32	63.11	5.11
Nano Si (25%) 1 cm / Lit.	96.12	7.86	98.42	7.72
Nano Si (25%) 2 cm / Lit.	85.23	7.32	82.55	7.02
Si (25%) 4 cm / Lit.	79.56	6.62	78.72	6.30
Si (25%) 5 cm / Lit.	74.38	6.21	70.22	6.09
L.S.D. at 5 %	5.78	0.42	5.44	0.35

Table (6): Effect of different silicon treatments on chlorophyll content and chemical composition of sweet pepper leaves.

Treatments	2013 Season				2014 Season			
	Total chlorophyll (SPAD)	N (%)	P (%)	K (%)	Total chlorophyll (SPAD)	N (%)	P (%)	K (%)
Control	38.45	0.98	0.42	1.10	37.33	0.93	0.43	1.09
Nano Si (25%) 1 cm / Lit.	49.23	1.73	0.72	2.01	47.54	1.70	0.75	1.99
Nano Si (25%) 2 cm / Lit.	47.12	1.56	0.70	1.82	45.32	1.51	0.73	1.78
Si (25%) 4 cm / Lit.	44.07	1.48	0.66	1.71	44.09	1.46	0.68	1.60
Si (25%) 5 cm / Lit.	43.67	1.42	0.50	1.52	42.11	1.39	0.55	1.43
L.S.D. at 5 %	4.12	0.21	0.07	0.08	3.84	0.19	0.09	0.06

Discussion:

It is evident that Si is beneficial for growth of many plants under various abiotic (e.g. salt, drought and metal toxicity) and biotic (plant diseases and pests) stresses[21,22]. Some authors reported that Si could ameliorate salt stress depression on plant species[23,24,25,26]. Indeed our results showed that the application of silicon improved all plant growth aspects under saline conditions. [27]observed that Si application leaded to balance growth reduction of *Phaseolus vulgaris* L. caused by salinity like decrease stomatal conductance, drop of leaf RWC, decrease K^+ tissues contentand etc. Our results on leaf fresh and dry weights as well as potassium contents confirm these results. Among the possible mechanisms of Si mitigation to stress is that it maintains the plant water Status under saline conditions which resulted in higher cell expansion and leaf area compared to Si-untreated plants grown under saline conditions[27]. This may explain the increment in plant height of Si treated plants compared to untreated one under salinity conditions. [29]found that plants treated with NaCl in the presence of Si showed values of turgor potential 42% higher than those plants treated only with NaCl. This may result also in higher stomatal conductance hence higher photosynthesis which may lead to higher dry matter production. In fact this may explain our result of the dry weight of the leaves. [28]reported that leafturgor potential and net photosynthesis rates were found 42 and 20% higher respectively in salt-stressed plants treated with Si in comparison to plants grown in Si free solution. Higher chlorophyll content reported in this study contribute further in improving photosynthesis rate and dry matter production for Si treated plants compared to control. Improvement in water content and net photosynthesis rates must be reflected on fruit yield and this is exactly what was found in this study with Si treated plants grown in saline media compared to untreated plants. Increment in nutrient contents such as N, P and K in plant tissue is another mechanism of Si mitigation to salinity stress. Si reduces uptake of Na^+ by improving K^+: Na^+ and also alleviates the toxicity of other heavy metals[29,30].

The effects of Si treatments on saline stress plants have been confirmed in our study on sweet pepper plants. However, the nano silicon form has proved a stronger mitigating effects compared to regular silicon form. Nano silicon was used earlier by[31] who found that it could enhance the growth of soybean. They observed that soybean seeds which treated by a mixture of Nano SiO_2 and Nano TiO_2 had more germination and the activity of nitrate reductase, superoxide dismutase, catalase and peroxidase of germinating seeds were increased significantly. [10]reported a more beneficial effects of nano Ca compared to chleated Ca on mitigation of salinity stress on tomato plants. This has been also noticed in this study with the superiority of nano silicon effects compared to regular silicon on mitigation of stress damages. This may be due to the fact that changing the particles to nano form can change physic–chemical properties compared to their bulk materials, they have a great surface area than bulk materials. Because of these larger surface areas, their solubility and surface reactivity was higher[20]. By manufacturingthe preparation ways of nanomaterials can change their characteristics, for example, the addition of nanoparticlesin liquid changes their chemical, physiological and transport characteristics compared to their base fluids such as enhancement of thermal conductivity[21]. This may mean more availability to plant absorption and higher reactivity within plant tissue.

Conclusion:

It could be concluded that application of silicon can mitigate salt stress damages on sweet pepper plants. However, the application of nano silicon is more effective and efficient compared to regular silicon application.

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