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Research Article
Role of Silicon Dioxide Nano Fertilizer in Mitigating Salt Stress on Growth, Yield and Chemical Composition of Cucumber (*Cucumis sativus* L.)

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Abstract
Background and Objective: Salinity either saline water of irrigation or saline soil is considered a major factor in limiting plant growth. Nano fertilizers are used to reduce drastic effect of salinity. This study was performed to limit salinity drastic effect on plant productivity and to study the effect of SiO_2 nano fertilizers foliar spray on growth parameter, yield, chemical composition of cucumber (*Cucumis sativa*) grown under agricultural drainage water. **Materials and Methods:** A field experiment was carried out in Kasr Rashwan village at Tameya province, Fayoum Governorate, Egypt during season (2015) to study the effect of SiO_2 nano fertilizers foliar spray at a rates of (0, 15, 30, 60 and 120 mg L^{-1}) on growth parameters, yield and chemical composition of cucumber (*Cucumis sativa*) under (agricultural drainage water). All data were subjected to an analysis of variance (One-way ANOVA) for a split-plot design, after testing for the homogeneity of error variances. Statistically significant differences between means were compared at $p \leq 0.05$. **Results:** The outcome data revealed an increase in plant height (cm), number of leaves/plant, fresh and dry weights of leaves/plant (g), number of fruits/plant, mean weight of fruit, fruit length and yield kg/plant total yield t ha^{-1} as compared with the untreated plants under agricultural drainage water. Data also, demonstrated that application a foliar spray of SiO_2 nanoparticle at rate of 60 mg L^{-1} gave a significant increase LSD<0.05 for most of growth parameter as compared to other treatments (15, 30 and 120 mg L^{-1}). **Conclusion:** Accordingly, results indicated increase in nitrogen and phosphorus, content and uptake and decrease in Na content and uptake when adding SiO_2 nano fertilizer. This study has identified that Silicon dioxide nano fertilizer can have a positive effect on the growth of plant and yield of cucumber.

Key words: Salinity-SiO_2 nano fertilizer, cucumber plant, growth parameters, yield, nutrient content and uptake

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Salinity is considered a major factor in limiting plant growth, crop productivity and salinization of irrigated and surrounding areas in the arid tropics and sub-tropics has not been diminished[1,2]. One of the main challenges in Egyptian agriculture is to use saline drainage water for crop production. Many studies[3,4] proved that saline drainage water not suitable for irrigation causing harm to crops and soils unless proper management strategies are established. These strategies include adopting advanced irrigation technology, selecting appropriately salt-tolerant crops and leaching salts below the crop root[3,4].

Cucumber (*Cucumis sativus* L.) is a major vegetable crop worldwide and develops rapidly with a shorter time from planting to harvest[5-7]. In Egypt, cucumber is needed for exportation and for local consumption and considered as one of the most valuable and economic vegetables.

Nano fertilizers in plant nutrition are one of the major roles of nanotechnology in agriculture, soil and water sciences[8]. Application of nano fertilizers is one of the promising methods for increasing resources use efficiency and reducing environmental pollutions. The use of nano fertilizers encouraged plant growth, production and reduces the toxicity of the soil. Also the use of nano fertilizers reduces the negative effects, caused by the excessive consumption of fertilizers and reduces the frequency of application of fertilizer[9-11]. Some nanoparticles are reported to be useful in increasing plants productivity grown under adverse conditions as silicon dioxide (SiO_2).

Recently, silicon has given a lot of attention by the agricultural researchers[12]. It had been reported that silicon might play a critical role in increasing plant's tolerance against environmental stresses. Hence, silicon affects plant growth under stressed conditions by affecting a variety of processes including the plant water relations[13,14] changes in ultra-structure of leaf organelles[15], upregulation of plant defense system and mitigation of specific ion effect of salt[16,17]. One of the alternative methods involving alleviation of negative stress effects might be application of silicon as a foliar fertilizer. Leaf fertilization with soluble Si sources seems promising to supply this element to plants for its effectiveness and feasibility, low doses lower cost, ease of application and good quality of fertilizers used (no contaminants). The reported experiment was performed to limit the salinity drastic effect on plant productivity and to study the effect of SiO_2 nano fertilizers foliar spray on growth parameter, yield and chemical composition of cucumber (*Cucumis sativa*) grown under agricultural drainage water.

MATERIALS AND METHODS

Experimental layout: A field experiment was carried out in Kasr Rashwan village at Tameya province, Fayoum Governorate, Egypt during season (2015) to study the effect of (SiO_2)-fertilizers foliar spray on growth parameters, yield, chemical composition of cucumber (*Cucumis sativa*) grown under agricultural drainage water. The investigated soil under experiment was of the following characteristics 24.3% sand, 20.1% silt, 55.6% clay, pH 8.88 and EC 4.23 dSm^{-1} at 25°C, $CaCO_3$ 3.97. The chemical analysis of the drainage water source used for irrigation was found in as follows: pH 8.49, EC 3.78, dSm^{-1}, Ca 10.3, Mg 4.66, Na 22.8, K 0.55, HCO_3 23.01, SO_4 10.40 and Cl 4.23 meq L^{-1}.

Treatments: Cucumber plants (*Cucumis sativus* L.) cv. Amaco green were obtained from Agricultural Research Centre, Egypt. Nanosized foliar spray of SiO_2 with different concentrations (15, 30, 60 and 120 mg L^{-1}) in addition to control (0) concentration, without using silicon dioxide nano fertilizer cucumber seeds were sown in plots of area $4\ m \times 5\ m$ at April, 2015, plots were arranged in a Completely Randomized Block Design (CRBD) with five replications. The area of each replicate plot was 4×5 m. The recommended NPK fertilizers were applied according to the recommendations of Ministry of Agriculture in Egypt. Cucumber seedlings with two leaves were transplanted by hand in double rows with 0.9 m row spacing and 0.3 m seedling spacing. During the growing period, plants were watered with mixture drainage water irrigation with tap water as ratio 2:1.

Measurements: At the harvest, vegetative growth parameters i.e., plant height (cm), number of leaves/plant and fresh and dry weights of leaves/plant (g), number of fruits/plant, mean weight of fruit, fruit length, fruit diameter and yield kg/plant total yield t ha^{-1} for each treatment were recorded, plant parts were dried at 70°C dry weights, were recorded before grinding. The following chemical analyses were determined nitrogen, phosphorus and potassium according to the method described by Cottenie *et al.*[18].

Statistical analysis: Collected data were subjected to statistical analysis of variance with five replicates as the experimental design was arranged in a Completely Randomized Block Design (CRBD) according to Snedecor and Cochran[19] at a significance Level of 0.05. All data were subjected to an analysis of variance for a split-plot design, after testing for the homogeneity of error variances. Statistically significant differences between means were compared at $p \leq 0.05$.

The physical properties of the soil were as follows (Particle size distribution or Soil Texture (Sand, Silt and Clay%), Field Capacity (FC), Permeability Wilting Point (PWP), available water, Hydraulic Conductivity (HC) and Bulk Density (BD) and chemical properties of the soil as follows (pH, EC, Ca^{++}, Mg^{++}, Na^{+}, K^{+}, CO_3^{-}, HCO_3^{-}, SO^{4-} and Cl^{-})) were determined according to Chapman and Pratt[20].

RESULTS

In the present study data presented in Table 1 it was observed that plant growth characters were badly affected by agricultural drainage water.

Also, pointed out data in Table 1 proved that application of foliar spray SiO_2 at the rates of (15, 30, 60 and 120 mg L^{-1}) increased plant height (cm), number of leaves/plant and fresh and dry weights of leaves/plant (g), number of fruits/plant, mean weight of fruit, fruit length, fruit diameter and yield kg/plant and total yield t ha^{-1} as compared with the untreated plants under agricultural drainage water. The effect of SiO_2 nano fertilizers foliar spray in small amounts can be beneficial in increasing cucumber growth. In the present study the SiO_2 nano fertilizers, levels of 15 and 30 mg L^{-1} SiO_2 proved to be effective under salinity (agricultural drainage water) when compared to control non-sprayed plants.

Comparing between different rates of SiO_2 nanoparticle (15, 30, 60 and 120 mg L^{-1}), data demonstrated that application a foliar spray of SiO_2 nanoparticle at the rate of 60 mg L^{-1} gave a positive increase in most of growth parameters as compared to the treatments. Plant height reached maximum 64.5 cm, number of leaves 23.00, number of fruits/plant 12.66, fruit length 13.57 cm, fruit weight 62.36 g, fruit diameter 2.33 cm, plant fresh weight 208.26 g, shoot dry weight 33.3 g, fruit dry weight 8.66 g and total yield (t ha^{-1}) 13.07.

Concerning the effect of salinity on nutrients concentration, the low values of N, P and K concentrations were recorded in shoots and fruit of cucumber plants grown under agricultural drainage water (Table 2, 3).

Data in Table 2 and 3 clearly revealed that at different rates of SiO_2 nanoparticle (15, 30, 60 and 120 mg L^{-1}) nutrient percentage in cucumber shoots for nitrogen reached maximum at 60 mg L^{-1} 1.7 als for P 0.19 and K 2.5 although Ca and Na were reduced compared to the control. The uptake percentage of nutrients in cucumber shoots N, P, K and Na increased compared to the control except for Ca the percentage uptake decreased compared to the control. The nutrient content and uptake in cucumber fruits represented in Table 3, results indicated that, nitrogen, phosphorus,

Table 1: Effect of SiO_2 nano fertilizers foliar spray on growth parameter, yield, of cucumber plants (*Cucumis sativus* L.) under agricultural drainage water

Treatments	Plant height (cm)	No. of leaves/plant	No. of fruits/plant	Fruit length (cm)	Fruit weight (g)	Fruit diameter (cm)	Total yield kg/plant	F.W of plant (g)	D.W of shoots (g)	D.W of fruit (g)	Total yield (t ha^{-1})
Control	49.86	15.33	6.21	8.34	45.27	1.77	1.15	173.30	23.24	5.30	6.21
15 mg L^{-1} SiO_2	51.66	17.67	8.33	9.43	49.53	1.92	1.80	181.27	26.20	6.80	8.75
30 mg L^{-1} SiO_2	56.33	21.33	10.44	10.36	54.30	2.26	2.50	190.23	29.90	7.93	11.84
60 mg L^{-1} SiO_2	64.50	23.00	12.66	13.57	62.36	2.33	2.71	208.26	33.30	8.66	13.07
120 mg L^{-1} SiO_2	58.11	21.66	12.11	11.32	54.47	2.16	2.37	197.50	30.46	7.40	11.50
LSD 0.05	7.57	7.24	2.35	3.08	5.11	NS	0.81	13.42	5.36	1.36	3.12

Table 2: Effect of SiO_2 nano fertilizers foliar spray on some macronutrients (%) and uptake (mg $plant^{-1}$) in shoots of cucumber plants (*Cucumis sativus* L.) grown under agricultural drainage water

	Nutrient content (%)					Uptake (mg $plant^{-1}$)				
Treatments	N	P	K	Ca	Na	N	P	K	Ca	Na
Control	1.1	0.14	1.7	3.1	2.8	255.2	32.48	394.4	719.2	649.6
15 mg L^{-1} SiO_2	1.5	0.16	2.1	2.6	2.8	393.0	41.92	550.2	681.2	733.6
30 mg L^{-1} SiO_2	1.7	0.16	2.3	2.2	2.5	508.3	47.84	687.7	657.8	747.5
60 mg L^{-1} SiO_2	1.7	0.19	2.5	2.1	2.1	566.1	63.27	832.5	699.3	699.3
120 mg L^{-1} SiO_2	1.4	0.21	2.1	2.4	2.3	424.2	63.63	636.3	727.2	696.9

Table 3: Effect of SiO_2 nano fertilizers foliar spray on some macronutrients (%) and uptake (mg $plant^{-1}$) of cucumber plants (*Cucumis sativus* L.) fruits grown under agricultural drainage water

	Nutrient content (%)					Uptake (mg $plant^{-1}$)				
Treatments	N	P	K	Ca	Na	N	P	K	Ca	Na
Control	1.9	0.21	2.9	1.7	2.1	100.7	11.13	153.7	90.1	111.3
15 mg L^{-1} SiO_2	2.2	0.27	3.5	1.5	1.8	149.6	18.36	238.0	102.0	122.4
30 mg L^{-1} SiO_2	2.4	0.28	3.7	1.3	1.6	184.8	21.56	284.9	100.1	123.2
60 mg L^{-1} SiO_2	2.6	0.35	3.7	1.1	1.4	223.6	30.10	318.2	94.6	120.4
120 mg L^{-1} SiO_2	2.2	0.33	3.3	1.3	1.7	162.8	24.42	244.2	96.2	125.8

potassium contents increased as using silicon dioxide foliar spray compared to the control although Ca and N contents were reduced compared to the control and uptake of N, P, K Ca and Na increased reaching maximum at 60 mg L^{-1} reaching 223.6, 30.1, 318.2, 94.6 and 120.4, respectively.

Generally, increased K uptake and decreased Na uptake by addition of nano Si was the major mechanisms responsible for better growth of plants under salinity.

DISCUSSION

Plant growth characters were badly affected by agricultural drainage water due to high concentration of (Na and CL ions) toxicity and ionic imbalance takes place in the cells due to excessive buildup of Na+ and Cl^-, which affects the uptake of other mineral nutrients[21-24].

Silicon seemed to improve plant salt tolerance which is attributed to selective uptake and transport of potassium and sodium by plants. Obtained results are in agreement with those recorded by Suriyaprabha *et al.*[25], Fatemi *et al.*[26], Kalteh *et al.*[27] and Siddiqui *et al.*[28]. Scientists observed that silicon application could ameliorate salinity damages on plant species. Also, Zurccani[29] observed that Si application led to balance growth reduction of *Phaseolus vulgaris* L. caused by salinity through decrease in stomatal conductance, drop of leaf, decrease K+ tissues content etc. In addition, applying Si to plants under salt stress could increase antioxidative enzymes activity, which might play great role to counter balance salinity damages[30].

The findings of some researchers reported a number of positive effects of Si on growth of cucumber plants such as more leaf thickness, more dry matter per unit area of leaf, a small but significant added increment in root fresh and dry weight and less propensity of leaves to wilt[31,32]. The SiO_2 nanoparticle at the rate of 60 mg L^{-1} gave a positive increase in most of growth parameters as compared to other treatments. These results were supported by Amirossadat *et al.*[32] and Azimi *et al.*[33].

Researchers observed that high dose of Silicon caused a decrease in plant height. Suggestions were made for Si application under saline conditions as it might help in increasing cell wall rigidity and strength and also cell wall elasticity during growth extension. Growth reduction might be attributed to the nutritional imbalance caused by Si high concentration or by the accompanying ions (calcium, potassium and sodium) that compete for the same absorption sites of other nutrients. Savvas *et al.*[14] and Amirossadat *et al.*[32] they observed that high dose of Silicon caused a decrease in plant height. Suggestions were made for Si application under saline conditions as it might help in increasing cell wall rigidity, strength and also cell wall elasticity during growth extension. Low values of both N, P and K concentrations were recorded in shoots and fruit of cucumber plants grown under agricultural drainage water. It is important to point out that, chloride or sodium salts might be implicated indirectly in decreasing N and K concentrations[33]. Decrease of nitrogen especially nitrate nitrogen might be related to the antagonistic relation between toxic[34] Cl^- and NO_3^-. The increase in N, P and K might be attributed to the positive effect of foliar application of SiO_2 nanoparticle, which consequently increased the absorption of different nutrients and alleviating the harmful effects of salinity. These results are in agreement with previous investigation indicated by Siddiqui *et al*.[35], Gui *et al*.[36] and Lui *et al*.[37]. It has been detected that, SiO_2 nanoparticle as foliar application avoided leaching loss of N and helped in more accumulation of nitrogen in leaf. Similar results were observed by Silicon rendered more P available to the plants reversing its fixation as silicon itself competed for P fixation and thus slowly released P helped in more accumulation of P content in leaf. Data also noticed that addition of SiO_2 nanoparticle significantly (LSD at level 0.5%) decreased sodium and calcium content and uptake under salt stress. Kardoni *et al*.[38] and Farooqui *et al*.[39] they found that the reduced uptake of sodium and calcium by plants could be explained at least partly by the inhibitory effect of silicon on the transpiration rate. Also, Vasanthi *et al*[40] and Liang *et al*.[41] they had concluded that silicon slows down Na uptake and increase the K uptake which in turn increase vegetative growth. Addition of SiO_2 nanoparticle as foliar application increased the Si concentration in both shoots and fruits of cucumber plants grown under agricultural drainage water unstressed conditions. The role of silicon as a beneficial mineral nutrient for reproductive growth of plant is well-documented.

CONCLUSION

It was concluded that agriculture, climate, sustainable use of natural resources, environmental factors, urbanization, accumulation of pesticides and over use fertilizers are the most important problems of modern agriculture. New techniques and methods have been used in-order to avoid the detrimental effects of these factors. The nanomaterial is one of the new-technologies that is being used in agriculture production and almost all areas of our lives. The researchers indicate many of potential benefits of nanotechnology.

SIGNIFICANCE STATEMENTS

This study will help researchers to explore the field of nano technology in agriculture. Nano fertilizers as silicon dioxide can have a positive effect on the plant growth and yield of cucumber, grown under saline conditions. Nano fertilizer use is important to limit salinization intrusion in cultivated lands.

REFERENCES

1. Munns, R. and M. Tester, 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol., 59: 651-681.
2. Parvaiz, A. and S. Satyawati, 2008. Salt stress and phyto-biochemical responses of plants: A review. Plant Soil Environ., 54: 89-99.
3. Mady, A.A. and M.I. Meleha, 2007. Increasing water use efficiency of berseem (*Trifolium alexandrinum* L.) as affected by methods of sowing and nitrogen fertilizer dosages. Egypt. J. Agron., 29: 1-15.
4. Yassen, A.A., E.F. Abdallah and M.S. Gaballah, 2011. Response of sunflower plants to nitrogen fertilizers and phytohormones under drainage water irrigation. Aust. J. Basic Applied Sci., 5: 801-807.
5. Liu, J.J., S.H. Lin, P.L. Xu, X.J. Wang and J.G. Bai, 2009. Effects of exogenous silicon on the activities of antioxidant enzymes and lipid peroxidation in chilling-stressed cucumber leaves. Agric. Sci. China, 8: 1075-1086.
6. Sacala, E., A. Demczuk, E. Grzys and Z. Spiak, 2008. Effect of salt and water stresses on growth, nitrogen and phosphorus metabolism in *Cucumis sativus* L. seedlings. Acta Soc. Botanicorum Poloniae, 77: 23-28.
7. Wehner, T.C., 2007. Cucumbers, Watermelon, Squash and Other Cucurbits. In: Encyclopedia of Food Culture, The Gale Group (Ed.)., The Gale Group Inc., USA., pp: 474-479.
8. Baruah, S. and J. Dutta, 2009. Nanotechnology applications in pollution sensing and degradation in agriculture: A review. Environ. Chem. Lett., 7: 191-204.
9. Naderi, M.R. and A. Abedi, 2012. Application of nanotechnology in agriculture and refinement of environmental pollutants. J. Nanotechnol., 11: 18-26.
10. Khot, L.R., S. Sankaran, J.M. Maja, R. Ehsani and E.W. Schuster, 2012. Applications of nanomaterials in agricultural production and crop protection: A review. Crop Prot., 35: 64-70.
11. Naderi, M.R. and A. Danesh-Shahraki, 2013. Nanofertilizers and their roles in sustainable agriculture. Int. J. Agric. Crop Sci., 5: 2229-2232.
12. Haghighi, M., Z. Afifipour and M. Mozafarian, 2012. The effect of N-Si on tomato seed germination under salinity levels. J. Biol. Environ. Sci., 6: 87-90.
13. Romero-Aranda, M.R., O. Jurado and J. Cuartero, 2006. Silicon alleviates the deleterious salt effect on tomato plant growth by improving plant water status. J. Plant Physiol., 163: 847-855.
14. Savvas, D., D. Giotis, E. Chatzieustratiou, M. Bakea and G. Patakioutas, 2009. Silicon supply in soilless cultivations of zucchini alleviates stress induced by salinity and powdery mildew infections. Environ. Exp. Bot., 65: 11-17.

15. Parveen, N. and M. Ashraf, 2010. Role of silicon in mitigating the adverse effects of salt stress on growth and photosynthetic attributes of two maize (*Zea mays* L.) cultivars grown hydroponically. Pak. J. Bot., 42: 1675-1684.
16. Liang, Y., W. Zhang, Q. Chen, Y. Liu and R. Ding, 2006. Effect of exogenous silicon (Si) on H^+-ATPase activity, phospholipids and fluidity of plasma membrane in leaves of salt-stressed barley (*Hordeum vulgare* L.). Environ. Exp. Bot., 57: 212-219.
17. Bharwana, S.A., S. Ali, M.A. Farooq, N. Iqbal, F. Abbas and M.S.A. Ahmad, 2013. Alleviation of lead toxicity by silicon is related to elevated photosynthesis, antioxidant enzymes suppressed lead uptake and oxidative stress in cotton. J. Bioremed. Biodegrad., Vol. 4. 10.4172/2155-6199.1000187.
18. Cottenie, A., M. Verloo, L. Kiekens, G. Velgh and R. Camerlynck, 1982. Chemical Analysis of Plant and Soils. Laboratory of Analytical and Agrochemistry, State University of Ghent, Belgium, pp: 100-129.
19. Snedecor, G.W. and W.G. Cochran, 1990. Statistical Methods. 7th Edn., Iowa State University Press, Ames, IA., USA.
20. Chapman, H.D. and P.F. Pratt, 1961. Methods of Analysis for Soils, Plants and Waters. University of California, USA., pp: 5-6, 56-58.
21. Solatni, Z., F. Shekari, K. Jamshidi, R. Fotovat and R. Azimkhani, 2012. The effect of silicon on germination and some growth characteristics of salt-stressed canola seedling. Int. J. Agron. Agric. Res., 2: 12-21.
22. Cavagnaro, J.B., M.T. Ponce, J. Guzman and M.A. Cirrincione, 2006. Argentinean cultivars of *Vitis vinifera* grow better than European ones when cultured *in vitro* under salinity. Biocell, 30: 1-7.
23. Song, J., X. Ding, G. Feng and F. Zhang, 2006. Nutritional and osmotic roles of nitrate in a euhalophyte and a xerophyte in saline conditions. N. Phytol., 171: 357-366.
24. Sabetteymoori, M., H.M. Khazaei, M. Nasiri and A. Neami, 2009. Effect of different levels of salinity on yield and yield component of single plant, morphological characteristics and leaf chlorophyll content of sesame (*Sesamum indicum* L.). J. Environ. Stress Agric., 2: 22-31.
25. Suriyaprabha, R., G. Karunakaran, R. Yuvakkumar, V. Rajendran and N. Kannan, 2012. Silica nanoparticles for increased silica availability in maize (*Zea mays* L.) seeds under hydroponic conditions. Curr. Nanosci., 8: 902-908.
26. Fatemi, L., S. Tabatabai and J. Fallahi, 2009. Effect of silicon on photosynthesis intensity and nutrient concentration of strawberry plants under saline conditions. J. Sustain. Agric., 19: 107-118.
27. Kalteh, M., Z.T. Alipour, S. Ashraf, M.M. Aliabadi and A.F. Nosratabadi, 2014. Effect of silica nanoparticles on basil (*Ocimum basilicum*) under salinity stress. J. Chem. Health Risks, 4: 49-55.
28. Siddiqui, M.H., M.H. Al Whaibi, M. Faisal and A.A. Al Sahli, 2014. Nano silicon dioxide mitigates the adverse effects of salt stress on *Cucurbita pepo* L. Environ. Toxicol. Chem., 33: 2429-2437.
29. Zuccarini, P., 2008. Effects of silicon on photosynthesis, water relations and nutrient uptake of *Phaseolus vulgaris* under NaCl stress. Biol. Plant., 52: 157-160.
30. Wang, X., Z. Wei, D. Liu and G. Zhao, 2011. Effects of NaCl and silicon on activities of antioxidative enzymes in roots, shoots and leaves of alfalfa. Afr. J. Biotechnol., 10: 545-549.
31. Yin, L., S. Wang, J. Li, K. Tanaka and M. Oka, 2013. Application of silicon improves salt tolerance through ameliorating osmotic and ionic stresses in the seedling of *Sorghum bicolor*. Acta Physiol. Plant., 35: 3099-3107.
32. Amirossadat, Z., A.M. Ghehsareh and A. Mojiri, 2012. Impact of silicon on decreasing of salinity stress in greenhouse cucumber (*Cucumis sativus* L.) in soilless culture. J. Biol. Environ. Sci., 6: 171-174.
33. Azimi, R., M.J. Borzelabad, H. Feizi and A. Azimi, 2014. Interaction of SiO_2 nanoparticles with seed prechilling on germination and early seedling growth of tall wheatgrass (*Agropyron elongatum* L.). Polish J. Chem. Technol., 16: 25-29.
34. Guntzer, F., C. Keller and J.D. Meunier, 2012. Benefits of plant silicon for crops: A review. Agron. Sustain. Dev., 32: 201-213.
35. Siddiqui, M.H. and M.H. Al-Whaibi, 2014. Role of nano-SiO_2 in germination of tomato (*Lycopersicum esculentum* seeds mill.). Saudi J. Biol. Sci., 21: 13-17.
36. Gui, X., X. He, Y. Ma, P. Zhang and Y. Li *et al*., 2015. Quantifying the distribution of ceria nanoparticles in cucumber roots: The influence of labeling. RSC Adv., 5: 4554-4560.
37. Liu, P., L. Yin, S. Wang, M. Zhang, X. Deng, S. Zhang and K. Tanaka, 2015. Enhanced root hydraulic conductance by aquaporin regulation accounts for silicon alleviated salt-induced osmotic stress in *Sorghum bicolor* L. Environ. Exp. Bot., 111: 42-51.
38. Kardoni, F., S.J.S. Mosavi, S. Parande and M.E. Torbaghan, 2013. Effect of salinity stress and silicon application on yield and component yield offaba bean (Viciafaba). Int. J. Agric. Crop Sci., 6: 814-818.
39. Farooqui, A., H. Tabassum, A. Ahmad, A. Mabood, A. Ahmad and I.Z. Ahmad, 2016. Role of nanoparticles in growth and development of plants: A review. Int. J. Pharm. Bio. Sci., 7: 22-37.
40. Vasanthi, N., L.M. Saleena and S.A. Raj, 2014. Silicon in crop production and crop protection: A review. Agric. Rev., 35: 14-23.
41. Liang, Y., W. Sun, Y.G. Zhu and P. Christie, 2007. Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: A review. Environ. Pollut., 147: 422-428.