Role of Silicon in Sustainable Fruit Production under Stress Conditions: A Review

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ABSTRACT

Silicon is a beneficial element as it can significantly improve the growth, yield and quality of fruit crops through silicon-enhanced resistance to biotic and abiotic stress. Mechanisms involved in alleviation of abiotic and biotic stresses are stimulation of antioxidant system in plants, complexation or co-precipitation of toxic metal ions with Si, immobilization of toxic metal ions, exclude uptake of toxic metal ions and vacuolar compartmentation of metal ions. The ignorance of plant physiologists is because of the visible symptoms of either Si deficiency or toxicity are not apparent and because of the abundance of the element in nature. Whereas, repeated cropping and the constant application of chemical fertilizers such as nitrogen, phosphorus and potassium have depleted the amount of Si that is available to plants in the soil. Awareness of Si deficiency in soil is now being recognized as a limiting factor for crop production and application of silicon fertilizer is practised worldwide, however there is limited case study regarding use of silicon fertilizer in our country despite its many advantages.

Key words: Abiotic stress and biotic stress, Silicon.

Silicon (Si) is the second most abundant element in the earth’s crust and in soils whereas, the plant-available form of Si is usually low because of the extremely low solubility of alumino-silicate clay minerals. Although Si has been proved to be beneficial for the healthy growth and development of many plant species, it has not been considered as an essential element for higher plants. It is known to effectively mitigate various abiotic stresses such as manganese, aluminium and heavy metal toxicities and, salinity, drought, chilling and freezing stresses (Liang et al., 2007). Several countries use Si fertilizer to increase productivity and sustainable production. The ability of plant resistance against biotic and abiotic stress is due to the thick epidermal silicon-cellulose layer. Silicon increases drought tolerance in plants by maintaining plant water balance, photosynthesis activity, erectness of leaves and structure of xylem vessels under higher transpiration rates. Also, it is responsible for encouraging water transport and root growth under unfavorable conditions and promoting antioxidants defense system (Epstein and Bloom, 2005). Silicon provides protection against fungal diseases by strengthening cell walls, thus making it more difficult for the fungi to penetrate and colonize the plant (Datnoff et al., 2007). Silicon might also play an active role in enhancing host resistance to plant diseases by stimulating defense reaction mechanisms. Salinity stress is one of the most significant environmental stresses limiting agricultural production worldwide and fruit crops are relatively sensitive too. It affects the anatomical, physiological and enzymatic features of plants (Arslan et al., 2016). The resulting of saline condition of soil is due to the accumulation of chlorine and sodium ions, which leads to decrease in water potential. The resulting low water potential of the soil decreases plants ability to absorb nutritional elements, reduces photosynthesis and leaf expansion, ultimately leads to failure of plant growth and development. Silicon, by both limiting transportation of sodium to leaves and storing the sodium inside the root, can improve plants stability against salinity stress. This review paper describes the understanding of Si uptake, transport, accumulation and case studies to evaluate the benefits of Si in increasing the fruit crop production, particularly grown under stress.

Mechanisms of silicon uptake by the roots, their translocation and accumulation in tissues

Si is an integral part of plants and its concentration ranges from 0.1 to 10% in plant tissue on a dry weight basis and, this variation is the result of differing uptake and transport ability of Si. It has been reported that rice is an active accumulator of Si, whereas some dicots such as strawberry, cucumber and tomato are passive accumulator, which is due to the difference in density of transporters to transport Si from external solution to cortical cells among plant
species. The uptake of silicon take place in the form of monosilicic acids or its anion. Following uptake by the roots, silicon is translocated to shoots via xylem in the same form where, it gets polymerized into silica and deposited in the bulbiform cell and under the cuticle. In the shoot, silicic acid is highly concentrated due to water loss through transpiration and its polymerization, which converts silicic acid to colloidal silicic acid and finally to silica gel (Ma and Yamaji, 2006). Transpiration controls the distribution of silicon in shoots and more concentration of silicon is reported in older tissues as this element is immobile within the plants. Formation of cuticle-Si double layer take place in leaf blades as a 2.5 μm layer of silicon is deposited in the space immediately beneath the thin cuticle layer. There are two types of silicified cells present in rice leaf blades: silica cells and silica bodies or silica motor cells. Silica bodies are located on bulbiform cells, whereas silica cells are in vascular bundles and are dumbbell-like in shape. The process of formation of silica bodies from silica cells is called as silicification (Ma and Yamaji, 2006). The deposition of silicified cells are also observed in the epidermis and vascular tissues of the stem, leaf sheath and hull of rice. These depositions of Si are responsible for the protection of plants from multiple abiotic and biotic stresses.

ROLE OF SILICON IN FRUIT CROPS: CASE STUDIES

Grape

Zhang et al., (2017) conducted two-year field experiments to study the effects of different sources of silicate fertilizers applied on table grape yield, fruit quality and fruit commercial characteristics during storage period. For this, two table grape cultivars were tested with treatments including: (I) no silicate fertilizer (control), (II) steel slag fertilizer and (III) water-cooling slag fertilizer. The application rate of silicate fertilizer was 600 kg SiO₂ ha⁻¹. Fruit yield, cluster weight, berry weight, berry size (i.e. length and width) were significantly increased by application of silicon fertilizers (P < 0.05) in both cultivars. Table grape fruit yield was 13.5% higher in the treatment with either water-cooling slag fertilizer or steel slag fertilizer than in the control all along both years of observations. Silicon fertilization significantly improved fruit total soluble solids, the ratio of total soluble solids to titratable acidity (TSS/TA) and fruit firmness. Applying silicate fertilizer significantly extended the fruit shelf-life by decreasing fruit respiratory intensity, decay incidence and weight loss. Water-cooling slag fertilizer did not show a significant difference from steel slag fertilizer in grape yield and fruit quality. Our findings suggest that silicate fertilizer could prolong shelf-life of fruits and increase the yield and quality of grape in a calcareous grey desert soil. Similarly, Guixin et al., (2017) also suggested that the application of silicate fertilizer increases both yield, total soluble solid, the ratio of total soluble solid to titratable acidity and fruit firmness of table grapes (Vitis vinifera L.) grown on calcareous grey desert soil. Applying silicate fertilizer significantly extended the shelf life of fruits by decreasing the fruit respiratory intensity, decay incidence and weight loss.

Citrus

Huanglongbing disease (HLB) caused by phloem-limited bacteria is the reason for decline in citrus industry worldwide (Gottwald, 2010). As of now there is no cure for this disease, management of its vector, the Asian citrus psyllid (ACP), Diaphorina citri Kuwayama is of primary concern (Canales et al., 2016). An experiment was conducted by Augusto et al., (2018) to study the effects of foliar and soil applications of nutrients (Ca, K and Si) on controlling the population dynamics of Diaphorina citri in Tahiti Lime Trees. The treatments includes i) control, ii) clothianidin at a dose of 50 g active ingredient per hectare (chemical control) iii) Ca, K and Si foliar applications at a doses of 3ml, 3g and 2ml, respectively and iv) soil application of potassium nitrate and potassium silicate (1 kg /tree). Foliar applications were performed at 0 and 4 weeks after treatment (WAT), meanwhile soil fertilization occurred at the beginning (i.e. WAT). Minimum number of individuals was reported with the foliar application of calcium and silicon compared with control. As plant resistance is enhanced by these mineral nutrients and showed a similar efficacy to clothianidin, it could be considered as a complementary tools with in an integrated management program of Diaphorina citri.

Ibrahim and Al-Wasfy (2014) studied on the promotive impact of silicon and selenium with potassium and boron on fruiting of Valencia orange tree with four foliar sprays of boric acid @ 0.05% and/or potassium sulphate @ 0.5% either alone or in combination with potassium silicate @ 0.1% and sodium selenite @ 50 ppm. The focus of this study was to elucidate the synergistic effect of using silicon and selenium besides boron and/or potassium on fruiting of the tree. Using silicon in combination with potassium silicate and sodium selenite significantly enhanced growth characters and nutritional status of the plant as well as quality of the fruits.

Ramirez and Palou (2016) evaluated the most economically important citrus postharvest diseases, green mold caused by the fungus Penicillium digitatum. Oranges (Citrus sinensis L. ‘Lane Late’) were artificially inoculated in rind wounds with the pathogen and 24 h later immersed in aqueous solutions of 90 mMPSi at 20 or 50°C for 60 or 150 s. Treated fruit were incubated for 7 days at 20°C and then disease incidence (%) of infected wounds and lesion diameter (mm) were recorded. Dips at 20°C for 60s were selected as the most effective and practical treatment conditions. These treatments were then applied to Valencia’ oranges inoculated 24 h before and subsequently stored at 5°C and 90% RH for up to 6 weeks. Control fruit were dipped in water. At the end of the cold storage, PSI dips significantly reduced the incidence of green mold by 45% with respect to control fruit. Lesion diameter at the end of the cold storage was 200 and 98 mm on control and PSI-treated oranges.
respectively. They concluded that the postharvest PSI treatment showed potential as a new reduced-risk chemical treatment for cost-effective control of citrus green mold and can be used in integrated disease management programs to replace or reduce the use of conventional postharvest fungicides.

Habasy (2016) conducted a study to test the effect of different concentrations (0.05 and 0.1 and 0.2%) and frequencies of application (twice or thrice) of potassium silicate on fruiting of Navel orange trees. Two sprays of potassium silicate @ 0.1% on the middle of March and April gave the best results with regard to vegetative growth aspects, leaf pigments and nutrients, fruit setting %, yield and both physical and chemical characteristics of the fruits. Similarly, El- Gloshy et al. (2016) reported that the productivity, fruit quality and nutritional status of Washington Navel Orange trees were influenced by foliar application with salicylic acid and potassium silicate combinations. Best results were obtained with 0.2% potassium silicate x 200 ppm salicylic acid.

Mango

Ahmed et al., (2013) carried out an investigation on 18-years old Hindy Bisnarra mango tree with the spray of potassium silicate (0.05, 0.1 and 0.2 %), salicylic acid (50, 100 and 200 ppm) and their combinations (0.05 % + 50 ppm, 0.1% + 100 ppm and 0.2 % + 200 ppm, respectively) four times during each growing season at the first week of March, April, May and June. Among all the treatment combinations of potassium silicate at 0.2 % and salicylic acid at 200 ppm reported the maximum shoot length (11.8), number of leaves/shoot (14.0), leaf area (73.4 cm²), leaf content of N (1.71 %), P (0.28 %), K (1.41 %) and Mg (0.67 %), vitamin C (52.0 mg/100g pulp), reducing sugar (6.2 %), total sugar (12.0 %), non reducing sugar (9.5 %), acidity (0.157 %), vitamin C (18.3 %), total sugar (15.6), fruit weight (197.5 g), yield (47.0 kg), TSS (26.67 °Brix), pulp/peel ratio (7.44), acidity (2.5 %), total acidity (0.415) and found at par with the control. Similarly, Wills et al., (2015) studied the effect of different sources of silica on nutrient content of leaves and fruit of Alphonso mango (Mangifera indica L.) in lateritic soil at the College of Agriculture, Dapoli (Maharashtra). The application of thirteen treatments viz., T1(RDF i.e, FYM 10 kg, 3 kg urea:3 kg SSP : 2 kg and Sulphate of potash kg per tree-1), T2 (T1 + 2t calcium silicate hectare-1), T3 (T1 + 3t calcium silicate hectare-1), T4 (T1 + 4t Calcium Silicate hectare-1), T5 (T1 + Rice husk ash @ 1.0 kg tree-1),T6 (T1 + Rice husk ash @ 1.5 kg tree-1), T7 (T1 + Rice husk ash @2.0 kg tree-1), T8 (T1 + Silixol spray @ 0.5 ml L-1), T9 (T1 + Silixol spray @ 1.0 ml L-1), T10 (T1 + Silixol spray @ 1.5 ml L-1), T11 (T1 + Potassium silicate spray @ 0.5 per cent), T12 (T1 + Potassium silicate spray @ 1.0 per cent) and T13 (T1 + Potassium silicate spray @ 1.5 per cent) was performed through spraying during initial stages of fruit growth (before flowering and 15, 30, 45 and 60 DAF). According to them best performance in terms of growth, yield and fruit quality parameters were recorded in T12, however the least was recorded in T1.

Sapota

A field experiment was conducted by Lalithya et al., (2013) at the College of Horticulture, Mudigere (Karnataka) to know the effect of silicon and micronutrients on growth and yield of sapota cv. Kalipatti under hill zone. Results highlighted that sapota spray treated with K₂SiO₃ @ 8ml/l was found better in improving number of shoots(23.96/m²), total chlorophyll content (4.87 mg/g of fresh weight), number of flowers (250.16/m²) and also minimized number of mumified fruits (34/tree).

Avocado

Kaluwa et al., (2011) conducted a study to investigate the application of silicon as a postharvest dip has an effect on the ripening pattern (firmness, carbon dioxide production and ethylene evolution) of ‘Hass’ avocado fruit. Avocado fruit is highly perishable due to relatively high rate of respiration, resulting into quick deterioration of fruit quality (Wills et al., 1989). In this study two different concentrations (1470 and 160 ppm) of four different sources of silicon (potassium silicate (K₂SiO₃), Nontox-Silica® (NTS), calcium silicate (Ca₃SiO₄) and sodium metasilicate pentahydrate (SiO₂Na₂.5H₂O)] were used. Fruits were stored at -0.5, 1, 5 or 25°C (room temperature) after 30 min dipping in to the respective silicon source. They reported that the postharvest applications of 1470 ppm Si in the form of KSiI at 5°C seem to be the most beneficial as respiration was most suppressed in this treatment. The amount of silicon found in the exocarp was high, in fruits treated with high Si concentrations, i.e., KSiI 1470 ppm, however there is no effect on the deposition of silicon in the mesocarp tissues.

Banana

Hanumanthaiah et al., (2015) studied the effect of soil and foliar application of silicon on fruit quality of banana cv. Neypoovan. Results revealed that banana fruit shelf life (6.33 days), TSS (26.87 °Brix), pulp/peel ratio (7.44), acidity
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(0.26%), reducing sugars (19.93 %) and non reducing sugars (2.24 %) were improved with the foliar application of Si @ 4ml and 2ml/l/plant at 15 days interval. Kumbarigire et al., (2015) also reported that application of diatomaceous earth (DE) as a source of silicon @ 750kg/ha + RDF, in banana showed positive effect on leaf nutrient status and yield attributing characters like finger length (20.03 cm), diameter of the fingers (3.85 cm), number of hands per bunch (11.13), number of fingers per bunch (195.38) and bunch weight (26.67 kg), in addition white fly infestation (15.41 %) and sigatoka leaf spot infestation (28.67 %) were minimized.

Date Palm

Moamen (2013) sprayed 0.025 to 0.1 % of royal jelly, 0.05 to 0.2 % potassium silicate and vitamins B1 250 ppm + Vitamin B6 at 100 ppm and Vitamin B12 at 250 ppm, either singly or in all possible combinations, four times viz., 1st is done at the start of growth, following 2nd after fruit set, 3rd and 4th after one month interval from the setting of fruits, and studied its effect on growth, leaf nutrient content, yield as well as physical and chemical characteristics of Sakkoti date palm fruits. The mixture containing royal jelly at 0.05 %, potassium silicate at 0.1 % and vitamins B (B1 at 250 ppm, B6 at 100 ppm and B12 at 250 ppm) gave the best results with regard to growth, leaf nutrient content, fruit yield and physiochemical characteristics of Sakkoti date palms. Similarly, El-Kareem et al., (2014) reported the best results on growth, yield and quality of fruits when combined applications of silicon and selenium was performed.

CONCLUSION

Silicon is an abundant element on Earth and its positive effects on plants make it important in agriculture and horticulture. It alleviates abiotic and biotic stresses and improves the yield and quality of fruit crops and helps in sustainable production. Identifying and implementing strategic Si nutrition management may play very well critical role in reversing declining yield trends in fruit crop production. The most important aspect for further studies on Si in plant biology should be focused on making full use of the role of Si in conferring tolerance in plants against abiotic stresses and thus its role in environmental remediation. There is need for applied research to quantify monosillicic and polysillicic acid contents to elaborate optimum Si rate, best time and methods of its application.

REFERENCES

Ahmed, F.F., Mansour, A.E.M., Mohamed, A.Y., Mostafa, E.A.M. and Ashour, N.E. (2013). Using silicon and salicylic acid for promoting production of HindyBisinnara mango trees grown under sandy soil. Middle East Journal of Agricultural Research. 2(2): 51-55.

Ahmed, M.M.A.A., Ahmed, Y.M.A. and Oraby, A.A.F. (2018). Yield and fruit quality of Ewaise mango trees grown under upper Egypt conditions as affected by application of nutrients, plant extracts, selenium and silicon. Researcher. 10(4): 11-20.

Arslan, D., Zencirci, N., Etoz, M., Ordu, B. and Bataw, S. (2016). Bread wheat responds salt stress better than einkorn wheat does during germination. Turkish Journal of Agriculture and Forestry. 40: 783-94.

Augusto, R.G., Ginja, P.P. and Hermann, R.D. (2018). An evaluation of the use of calcium, potassium and silicon for the management of Diaphorina citri populations in Tahiti lime trees. Not Bot Horti Agrobo. 46(2): 546-52.

Canales, E., Coll, Y., Hernandez, I., Porteles, R., Garcia, M.R., Lopez, Y. and Borras, H.O. (2016). ‘Candidatus Liberibacter-terasiasicus’, causal agent of citrus Huanglongbing, is reduced by treatment with brassinosteroids. PloS ONE. 11(1): 1-16.

Costa, I.J.S., Pereira, M.C.T., Mizobutsi, G.P., Maia, V.M., Silva, J.F., Oliveira, J.A.A., Oliveira, M.B., Souza, V.N., Nietsche, R.S., Santos, E.F. and Korndorfer, G.H. (2015). Influence of silicon fertilization on ‘Palmer’ mango tree cultivation. Acta Horticulturae. 1075: 229-234.

Datnoff, L.E., Rodrigues, F.A., Seebold, K.W. (2007). Silicon and plant disease. In: Mineral Nutrition and Plant Disease. American phytopathological Society, Saint Paul, USA, pp. 233-46.

El- Kareem, M.R.G., Abdel, A.A.M.K., Mohamed, A.Y. (2014). The synergistic effects of using silicon and selenium on fruiting of Zaghloul date palm (Phoenix dactylifera L.) International Scholarly and Scientific Research and Innovation. 8(3): 259-62.

El-Gioushy, S.F. (2016). Productivity, fruit quality and nutritional status of washington navel orange trees as influenced by foliar application with salicylic acid and potassium silicate combinations. Journal of Horticultural Science and Ornamental Plants. 8(2): 98-07.

Epstein, E. and Bloom, A.J. (2005). Mineral nutrition of plants: Principles and perspectives, Second edition: Sinauer, Sunderland, MA.

Gottwald, T.R. (2010). Current epidemiological understanding of citrus huanglongbing. Annual Review of Phytopathology. 48: 119-39.

Guixin, C., Mei, Z. and Yongchao, L. (2017). Applying silicate fertilizer increases both yield and quality of table grape (Vitis vinifera L.) grown on calcareous grey desert soil. Proceedings of abstracts, 7th International Conference on Silicon in Agriculture. 129 pp.

Habasy, R. (2016). Response of navel orange trees to potassium silicate application. Assiut Journal of Agricultural Sciences. 47: 164-72.

Hanumanthaiah, M.R., Hipparagi, K., Renuka, D.M., Vijendrakumar, R.C., Santhoshkumar, K.V. and Kumar, K.K. (2015). Effect of soil and foliar application of silicon on fruit quality parameters of banana cv. Neyypoovan under hill zone. Plant Archives. 15(1): 221-24.

Ibrahim, H.I.M. and Al- Wasty, M.M. (2014).The promotive impact of using silicon and selenium with potassium and boron on fruiting of valencia orange trees grown under Minia region conditions. World Rural Observations. 6(2): 28-36.

Kaluwa, K., Bertling, I. and Bower, J.P. (2011). Effect of postharvest silicon application on ‘Hass’ avocado fruit physiology. Acta
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Horticulturae. 911: 565-71.

Kumbargire, G.A., Swamy, G.S.K. and Bawoor, S. (2015). Influence of diatomaceous earth on yield with its attributing characters and quality of banana in the northern zone of the Karnataka. Research in Environment and Life Sciences. 8(4): 705-08.

Lalithya, K.A., Hipparagi, K., Thippeshappa, G. and Vishnuvardhana. (2013). Effect of silicon and micronutrients on growth and yield attributes of sapota cv. Kalipatti under hill zone. Crop Research. 46(1, 2 and 3): 146-49.

Liang, Y.C., Sun, W.C., Zhu, Y.G., Christie, P. (2007). Mechanisms of silicon- mediated alleviation of abiotic stresses in higher plants: A review. Environmental Pollution. 147: 422-28.

Ma, J.F. and Yamaji, N. (2006). Silicon uptake and accumulation in higher plants. Trends in Plant Science. 11(8): 392-97.

Moamen, M.A.W. (2013). Response of Sakkoti date palms to foliar application of royal jelly, silicon and vitamins B. Journal of American Science. 9(5): 315-19.

More, S.S., Gokhale, N.B., Shinde, S.E. and Korake, G.N. (2015). Effect of different sources of silica on nutrient content of leaves and fruit at different stages of Alphonso mango (Mangifera indica L.) in lateritic soil. Journal of Progressive Agriculture. 6(2): 1-9.

Ramirez, P.A.M. and Palou, L. (2016). Potassiumsilicate: A new organic tool for the control of citrus postharvest green mold. Acta Horticulturae. 42: 287-91.

Wills, R.B.H., McGlasson, W.B., Graham, D., Lee, T.H. and Hall, E.G. (1989). Postharvest: An introduction to the physiology and handling of fruit and vegetables. B.S.P. Professional Books, Oxford. 3rd Edition.

Zhang, M., Liangc, Y. and Chua, G. (2017). Applying silicate fertilizer increases both yield and quality of table grape (Vitisvinifera L.) grown on calcareous grey desert soil. Scientia Horticulturae. 225: 757-63.