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Soil and foliar application of silicon on quality parameters and yield of horticultural crops

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Abstract

Silicon (Si) is the second most common element on earth's crust. It comprises approximately 28% of the earth crust and supposed to be beneficial element to improve plant growth, development and productivity. Besides this, silicon is also helpful in promoting mechanical strength, light interception and resistance to various biotic and abiotic stresses, improving both quantity and quality of production. Although Si is universal in nature, evidence of its essence for higher plants is still lacking. According to scientific literature, however, Si is conducive to the healthy growth of plants directly or indirectly. Si may be applied through soil as well as foliar application. Under stressful conditions, it acts as a bio stimulant and exhibits optimistic results. Solubilization of silicon in situ in soil by silicate-solubilizing bacteria is also being attempted, and some bacterium is used as a biofertilizer to solubilize silicon and potassium bound in silicates. The use of silicon fertilizers provides rigidity and reverses the succulence induced by high nitrogen, paving the way for a higher crop yield. This review paper compiles till date available references and their importance for yield and quality of the most important horticultural crops, including recent developments and concentrated developments in the same field.

Keywords: Silicon, quality, yield, horticulture, recent developments

Introduction

Farmers use the land intensively without proper nutrient management practices, resulting in nutrient depletion in the soil, ultimately reduced yields. Also due to mismanagement of cultural practices or lack of some essential nutrients like N, P and K etc. The exogenous application of Si is not a routine practice as it is believed that the soil itself can sustain the supply of this nutrient. Unfortunately, the silica found in soil is in a polymerized form. First it should be depolymerized and then it is solubilized by biological or chemical reactions in the soil and at last it is available to the plant. Silicon is almost 146 times more abundant than carbon in the Earth's crust, but is rarely found in biological materials (Organic matter, biomass, living or dead biological matter etc.). Silica makes up 50-70% of soil mass and its content varies from less than 10% to almost 100% in soil. Briefly we can say all plants that are rooted in the soil may contain some Si in their body tissues. Silicon is supposed as "anomaly" plant nutrient because it is not essential for plant growth and development or metabolism (Epstein, 1994) [13]. However, soluble Si has been found to enhance the growth, development and yield of many plants. The content of silicon in plants is equal to or higher than the major nutrients N, P, K supplied by fertilizers. Plants may not be foolish to accumulate an element without any specific role in nutrition or physiology. It may share many properties of carbon, which forms the backbone of most organic molecules, but rarely forms an integral part of biomolecules. This is primarily because the Si–Si bonds are considerably weaker than C–C bonds and many Si–H bonds are relatively unstable and react readily with oxygen. The silicon atoms are larger in size (atomic radius 111 pm – picometers) compared to carbon (atomic radius 67 pm) also makes it unsuitable as a building block, although it can also form bonds with four other atoms, creating a three-dimensional network similar to carbon (Fig 1).

A peculiarity of the silicon atom makes it preferable to bind to four oxygen atoms rather than two double bonds, as suggested by SiO_2. The oxygen atoms form a tetrahedron. Silicon dioxide isn't really a molecule; it forms a huge covalent structure with a crystalline arrangement like this (quartz).

Yet a few organisms are able to absorb and accumulate silicon. The most notable ones are diatoms, cryophytes, silico flagellates, some xanthophytes, radiolarians, plants, insects and vertebrates (Heinen, 1962). Silicon based life was proposed and searched in extraterrestrial life as the living beings on earth, are solely carbon based. Silicon compounds played a minor role in the evolution of primitive life-forms. Especially, when earth was inhospitable to the evolution of carbon-based life-forms. All terrestrial forms (nematodes, bacteria etc.) contains some amount of silicon in their body and silicon free organisms are rare. Hence, we can state that there is no existence of carbon free life forms even leaf plant analysis of about 670 species of land plants belonging to 138 families showed the presence of 42 elements in the plant body. But plants require only 17 elements to complete their life cycle (Watanabe *et al.*, 2007) [58]. Silicon (Si) is not an essential element for animals, humans and higher plants, but it is considered as useful non-essential element (Liang *et al.*, 2015) [36]. Yamaji *et al.*, (2006) [40] also supported the fact that Si is not essential for the plant, but its beneficial effects regarding promoting in plant growth, especially under stressful conditions are significant. Since long ago, Si is receiving more and more attention due to its importance and beneficial effects in plant physiology. In molecular studies concerning about Si uptake and transport, it was found that a large group of proteins and genes with different properties in different plant species, are responsible for transportation from soil to root and from root to shoot. It may not be possible with the available knowledge to determine its exact role, requirements of silicon, although its beneficial effects on plant growth, suppressing pests and diseases, and increasing yield have been demonstrated.

Epstein *et al.*, (1999) [14] also considered silicon as agronomically beneficial element. This is due to resistance of plants to biotic (pathogens, insects and pests, etc.) and abiotic stress (drought, salt stress, freezing conditions) along with aluminum, manganese and heavy metals. It also increases drought tolerance in plants by maintaining plant water balance, photosynthetic activity, leaf erection and xylem vessel structure under transpiration rates (Melo *et al.*, 2003) [44]. Application of Si fertilizers to farmland, particularly those where Si is poorly available, is a common and routine agricultural practice in many countries such as India, China, Japan, Korea, Brazil and the USA to achieve higher productivity and sustainable production (Takahashi *et al.*, 2002) [45]. It is most commonly found in soils in solution form as silicic acid (Ma *et al.*, 2001). Silicon has positive growth impacts like increasing dry mass, yield and disease resistance (Gillman *et al.*, 2003) [19]. It also plays a positive role in recovering from the nutritional disorders in fruit. Liang *et al.*, (2007) [38] also revealed that application of silicon, especially foliar spray is safe for the environment and may also be used in organic farming.

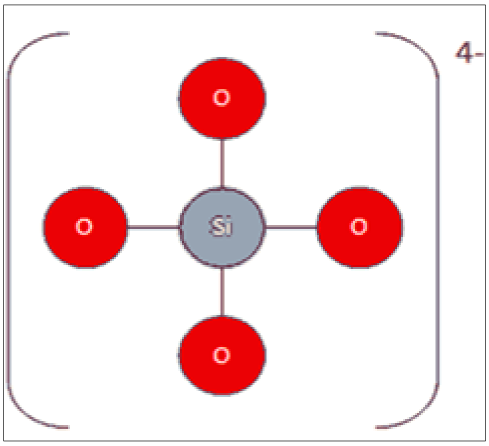


Fig 1: Structure of Silicon

Silicon sources

Application of Si is oftenly ignored with the belief that the soil itself can sustain its supply. Unfortunately, the silica found in soil, is in an unavailable polymerized form and must be depolymerized and solubilized in the soil through biological or chemical reactions, in order to be taken up by plants. Plants absorb Si exclusively as monosilicic acid (orthosilicic acid) through diffusion process and also through the impact of transpiration-induced root uptake (mass flow). The source of silica is from soil silicates. Applications of metal silicates to rice in Japan and to sugar cane in Brazil, are common practices. Although silicon is a very common element, still we need to supply it as a fertilizer. Regardless of what type of silicon source is used, it should have a relatively high silicon content that may provide sufficient available water-soluble silicon to meet the plant's needs, should be inexpensive, have a physical nature that facilitates storage and application, and should not contain any substances that pollute the soil. Harvest residues, particularly from silicon-storing plants such as rice, which can be used as sources of silicon after the harvest. Inorganic materials such as quartz, clay, mica, and feldspar are rich in Si, but are considered as poor sources of silicon fertilizer because of low solubility of the Si. Calcium silicate is obtained as a by-product of steel and phosphorus industries is one of the most commonly used silicon fertilizer. Potassium silicate source is expensive but which is highly soluble and may be used in hydroponics. Other commercially used sources are calcium silicate hydrate, silica gel and thermo phosphate (Table 1)

Table 1: Silicon sources that may be used in different nutrient solutions

Silicon source	Silicon content (%)
Potassium silicate	18%
Calcium silicate	24%
Calcium silicate slag	18-21%
Salicic acid	29%
Sodium silicate	23%
Quartz sand (fine grinded)	46%
Amorphous silica	-

Reference: Meena *et al.*, (2013) [42]

There are different views regarding application of silicon fertilization in plants like supplementation of plant nutrition with silicic acid may lead to increased tissue consistency and durability during post-harvest handling in strawberries (Fragaria×ananassa Duch) (Babini *et al.*, 2012) [7]. In addition to this Kamenidou *et al.*, (2010) [27] recorded improved floristic quality traits in gerberas with the application of Si fertilizer. Foliar application of Si as potassium silicate helps improve fruit characteristics such as fruit weight (99.96 g), fruit length (5.55 cm), fruit diameter cm), fruit volume (102.38 g), maximum shelf life (10 .90 days) and yield (12.48 t/ha) Sapota Thippeshappa *et al.*, (2013) [53]. Above all, soil application of calcium silicate at the rate of 2.5 kg/tree resulted in the highest cost-benefit ratio (2.36) in sapota (Lalithya *et al.*, 2014) [33]. Foliar application of silicon at 15 days intervals was found to be best in improving quality parameters related to shelf life (6.33 days), TSS (26.67 0Brix), pulp/peel ratio (7 .44), acidity (0.26%), reducing sugars (19.93%) and non-reducing sugars (2.24%) in banana (Hanumanthaiah *et al.*, 2015) [20].

The level of silica present in plants is equal to or sometimes also higher than that of the major nutrients (N, P and K).

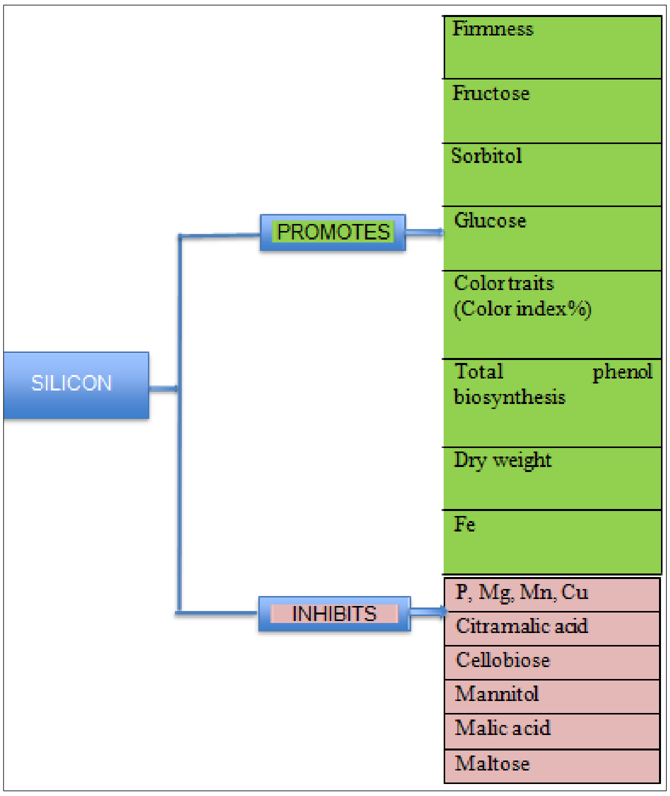
Higher plants differ characteristically in the absorption of Si. Some plants absorb more silicic acid than required and deposit on tissues hence it cannot be extracted from plants. It has been seen that silica concentration is higher in monocots than in dicots. It generally increases in following order- legumes<fruit crops<vegetables<grasses<grain crops. The aerial parts of the plant accumulate more Si compared to the roots.

Functions of silica in plants

Silica deposition on epidermal cells in leaves and stems confer rigidity, strength and non-lodging. Its deposition strengthens the vascular tissues, reduces transpiration and improves water balance potential resulting in water economy. Contrast to this, low silica levels lead to succulence and increase the rate of transpiration (water loss through the leaves), resulting in poor water use efficiency. It also improves phosphorus availability and uptake by competing with P fixation sites in soil.

It regulates uptake of iron, manganese, copper, chromium, sodium and aluminium etc. The toxicity of these elements in acidic soils can be counteracted by the application of soluble silica fertilizers. It increased root growth in grasses and yield increased in cereals, sugar cane, beets and cucumbers, pest and disease resistance in multiple crops has also been recorded. It also improves grain yield, reduces chaffiness and shattering in cereals.

Improved reproduction through improved pollination in tomatoes and better pollen fertility in cucurbits. However, silicon deficiency decreases protein and chlorophyll synthesis and increases the rate of photosynthesis, due to stronger stems that ultimately produce more upright leaves that intercept more sunlight.



Reference: Karagiannis *et al*., (2021) [24]

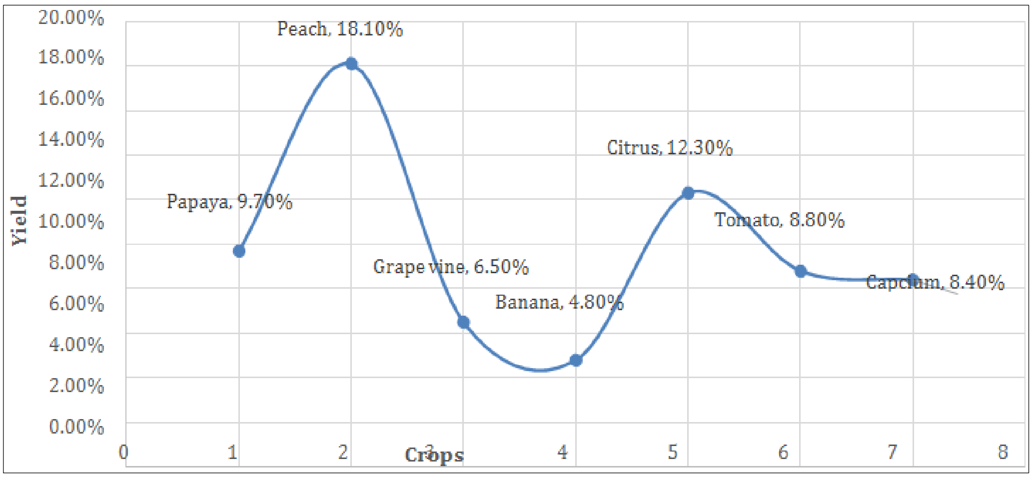
Fig 1: Systematic representation

Silicon in agricultural production

Availability of Si differs in concentration with soil type but it can be a major factor in limiting crop production. Plants with an enormous requirement for Si would show significant growth and yield reduction when grown in soils having low Si content. To overcome Si deficiency and boost crop production, several Si sources have been used, including slag-based silicates, soluble potassium or sodium silicates, slow-release potassium silicate made from feldspar. (Liang *et al*., 2015) [36]. It is well established that Si-based fertilizers can improve growth, yield and quality of a wide range of agricultural and horticultural crops (Guntzer *et al*., 2012) [18]. Si deficiency is one of the most important edaphic factors limiting the yield and quality of crops grown on heavily weathered tropical soils. Many other plant species of horticultural importance such as tomato, potato (*Solanum tuberosum*) and cherry tomato (*Lycopersicon cerasiforme*), sugar cane, etc. showed a positive response to Si fertilizer which improved plant growth and yields.

Mechanism of working

Slow-Release Behavior of SRPS (slow-release potassium silicate) in Soil: Liu *et al*., (2007) prepared a slow-release fertilizer (potassium silicate) to improve the consumption of fertilizer and water. Its core was K_2O_3Si in an alginate matrix, and the shell was poly (acrylic acid-co-acrylamide)/kaolin (P(AA-co-AM)/kaolin) superabsorbent polymer. It contained 26.6% K_2O and 10.4% SiO_2.They concluded that by using this product, absorption of water has been increased (85 times its own weight) for 90 min at room temperature. Non-fickian diffusion technique was revealed and they concluded that this product has good water-retention and slow- release of nutrients capacity. Moreover, it is environmentally friendly and non-toxic. That is why, it may be recommended in horticultural operations frequently.



Reference: Liu *et al*., (2011) [23]

Fig 1: Effects of slow release of potassium silicate on yield of various fruit crops

It was found that Si fertilization is effective in improving the quality of many vegetables and fruit crops. Liu *et al*., (2011) [23] reported that long-term field application of the slow-release potassium silicate from feldspar significantly increased the yield of crops such as papaya (*Carica papaya*), peach (*Prunus persica*), grapevine, banana, and citrus (*Citrus spp.)*, tomato, cabbage and chili (*Capsicum annuum*) (Fig).

S. No	Name of horticultural crops	Silicon source used	Impact of silicon source in crops	References
1.	Banana	Potassium silicate Calcium silicate	Improves quality parameters	Hanumanthaia h *et al*., 2015 [20]
2.	Banana	Potassium silicate	Controlled postharvest fungal rot and storability	Nikagolla *et al*., 2019 [48]
3.	Mango	Potassium silicate	Improves yield	Harhash *et al*., 2019 [1]
4.	Peach	Potassium silicate	Improved fruit physical characters	Aziz *et al*., 2021 [2]
5.	Strawberry	Potassium silicate	Improved growth, yield, quality and stress	Nada *et al*., 2020 [47]
6.	Avocado	Potassium silicate	Improves quality of fruit	Bower *et al*., 2010 [25]
7.	Melon	Calcium silicate	Enhanced resistance to bacterial fruit blotch (BFB) and elevated Ca and Mg levels in the plant tissue	Ferreira *et al*., 2015 [15]
8.	Tomato	Sodium silicate	Increases shelf life and yield	Tzortzakis *et al*., 2020 [10]

The maximum total soluble solids content in bananas (26,670 Brix) with (foliar application of potassium silicate with 4 ml L-1/plant at interval of 15days) while the lowest total soluble solids content (22,530 Brix) was found in the control. Silicon along with potassium helps to synthesize more sugars in the fruit, thus helps to incline overall total soluble solids Hanumanthaiah *et al*., (2015) [20]. The results are compatible with Bhavya *et al*., (2010) [9] and Hanumanthaiah *et al*., (2015) [20] in Bangalore Blue Grapes and Banana, respectively. Kumar *et al*., (2015) [29] explained that the increase in total soluble solids content weight due to potassium silicate played a prominent role in the translocation of photo (Co2, H2O2) assimilates, sugars and other soluble solids which are responsible for the increasing TSS of guava. Titratable acidity was lower (0.26 percent) in bananas by foliar application of potassium silicate at 2 mL L-1/plant at 15-day intervals, followed by soil application of calcium silicate at 1000 g/plant + foliar application of potassium silicate at 4 mL L- 1/plant 30 days apart. Similar observations were made by Bhavya *et al*., (2010) [9] who explained that an increase in total soluble solids in the berries led to a decrease in acidity. Potassium compound (silicon) neutralizes organic acids (citric acid, malic acid) and controls the acidity and pH of the fruit juice. The decrease in acidity could be due to an increase in total soluble solids and silicon may be responsible, which could either be involved in the rapid conversion of metabolites into sugars and their derivatives (Su *et al*., 2011) in apple. Weerahewa *et al*., (2015) [57] found a significantly lower percentage of total acidity (TA %) in tomatoes (cv Thilina) treated with 50 or 100 mg/L silicon, regardless of plant stage. Vijay *et al*., (2016) also reported in sweet orange that the increased sugar content minimizes acidity of the fruit. They found that the level of reducing sugars (19.93%) was higher with foliar application of potassium silicate at 2 mL L-1/plant after 15 days. Chaudhary *et al*., (2016) [11] also proved in Kinnow mandarin that silicon (helps) with sugar translocation in plants, and thus there by increases the reduction of sugar and total sugar. Maximum ascorbic acid content was found with soil application of calcium silicate at 1000 g/plant and foliar application of potassium silicate at 2 ml L-1/plant at interval 30days. The maximum days of maturation was observed with (foliar application of potassium silicate at 2 ml L-1/plant at interval of 15 days) (7.67 days). Above all early maturation by 6.00 days was recorded in the control. Jamali *et al*., (2011) [22] reported that the application of silicon resulted in a longer lifespan of the carnation as it decreased ethylene production. Potassium silicate application improved fruit quality due to the suppression of respiration and the reduction in ethylene evolution. It can be concluded that the application of potassium silicate has effectively helped in extension of the shelf life in fruits. Hanumanthaiah *et al*., (2015) [20] found that banana shelf life was prolonged when stored after treating with silicon sources. They concluded that foliar application of potassium silicate at 4 ml per liter at interval of 15 days, extended shelf life of banana up to 6.33 days, which was statistically comparable to other treatments, minimum number of days (5.11) was recorded in the control. Jamali *et al*., (2011) [22] reported that the use of silicon increased the vase life of carnations by decreasing ethylene production. Silicon formed complexes with organic compounds in the cell wall of epidermal layer and therefore increased their resistance against degrading enzymes. Hussien *et al*., (2021) [21] reported that treating sultani fig trees twice during (first week of April and May) with 2% potassium silicate resulted in promotion of yield quantitatively and qualitatively i.e., by increasing the number, length and thickness of the shoots and the number of leaves/shoots, leaf area and percentages of N, P, K, Ca etc was also improved.

Role of silicon in stress resistance

Beneficial effects of Si are more distinct under stress conditions. This is because Si is able to protect plants from various kinds of abiotic and biotic stresses. Numerous research studies have shown that Si is also very effective in managing diseases caused by both fungi and bacteria in different plant species. There are two mechanisms of Si that enhance resistance to diseases. According to one method, it acts as a physical barrier and its deposition takes place beneath the cuticle to form a cuticle–Si double layer. This layer mechanically improves penetration of fungi and thereby disrupt the infection process. Another mechanism is that soluble Si acts as a modulator of host resistance for pathogens. For example, in the roots of cucumber plants being infected and colonized by pythium while, Si enhanced the activity of chitinases, peroxidases and polyphenol oxidases enzymes. Such biochemical responses may be imparted by soluble Si, suggesting that it might play a significant role in enhancing host resistance against diseases by stimulating certain mechanisms of the defense system. Though several possible mechanisms have been proposed, still the exact nature of the interaction between soluble Si and biochemical pathways of the plant that leads to disease resistance, is unknown. A recent study shows that during the induction of systemic acquired resistance (SAR) in cucumbers, the expression of a gene encoding a novel proline-rich protein was enhanced. This protein has repeating C-terminal sequences that contain an unusually high number of amino acids, *viz*. lysine and arginine. The synthetic peptide derived from the repetitive sequences was able to polymerize orthosilicic acid into insoluble silica, which is involved in cell wall reinforcement at the site of fungal penetration of epidermal cells. This experiment provided a biochemical and molecular basis for Si-enhanced disease resistance. Silicon also manages many types of alleviates like abiotic stresses including chemical stress (salt, metal toxicity, nutrient imbalance) and physical stress (lodging, drought, radiation, high temperature, freezing and UV). Most of the beneficial effects are also attributed by Si deposition in cell walls of roots, leaves, stems and hulls. For example, Si deposition in roots reduces apoplastic bypass flow and provides binding sites for metals, which resulted in declined uptake and translocation of toxic salts and metals from roots to shoots. Si deposition in stems, leaves, and husks improves the strength and stiffness of cell walls and decreases the rate of cuticle transpiration and thus increases resistance to lodging, downswing, and scavenging. high temperatures, radiation, UV rays and drought stress. Under drought and salt stress, the relieving effects of Si have been linked to increased antioxidant defense capabilities. However, this could be a beneficial result of Si rather than a direct effect because Si is unlikely to affect the activity of antioxidant enzymes. In addition to Si's role in relieving various types of stress, Si also enhances light interception by keeping leaves upright, thus stimulating the rate of photosynthesis.

This is particularly important in dense plant populations and with heavy nitrogen fertilization to minimize mutual shading. Si has been reported to promote cell elongation but not cell division, likely as a result of Si-enhanced cell wall extensibility in rice. Crops growing in the field are constantly subjected to a number of stresses which Si could alleviate. Such plants accumulate large amounts of Si, since this element increases stress resistance, regardless of whether the plants are monocotyledonous or dicotyledonous. This is particularly important for plants accumulating high Si content, which disrupts growth, and for high production and sustained yield, on the other hand, low Si accumulation results in a significant reduction in yield and quality.

Table 4: Effects of the different foliar sprays with (a) silicates, (b) nano-silica on following characters.

Effects	Silicates	Nano silica
Infections (Biotic stress)	Positive effect	Positive effect
Abiotic stress	No effect	No sufficient data available
Plant growth	No effect	Positive effect
Leaf size	No effect	Positive effect
Yield	No effect	Positive effect
Quality of the produce	No effect	Positive effect

Reference: Laane *et al*., (2018) [32]

Conclusion

Si-based fertilizers are supposed to promote the crop yield and quality with significant economic advantages, however, large-scale application of Si fertilizers to the major field crops still has a long way to go. The addition of SRPS (slow-release potassium silicate) into soil may greatly improve the water-holding ability and water-retention property of the soil, as well as improve the availability of fertilizer and water resources to plants, simultaneously. Therefore, application of SRPS holds good scope in agriculture and in the renewal of arid and desert environments.

Research gap

More field trials should be performed to investigate the optimum addition rate of silicon to be applied in different soils and crops. In addition, more efforts should be made on research and develop cheaper and more effective Si-based fertilizers. Ecological issues of Si in both natural and agricultural ecosystems deserve more attention. Till now only some Si transporters have been identified in a few plant species hence, more research work is still needed to characterize Si transporters in most of plants and to improve Si accumulation level and subsequently generate broad beneficial effects in plants.

Reference

1. Ali M, Harhash MM, Mahmoud RI, Kabel SA. Effect of foliar application of potassium silicate and amino acids on growth, yield and fruit quality of 'keitte' mango trees. Journal of the Advances in Agricultural Researches. 2019;24(2):238-251.
2. Aziz MH, Soliman MA, Ennab HA. Effect of potassium silicate and chelated calcium sprays on yield, quality and

storage of peach fruits cv. "dessert red". Menoufia Journal of Plant Production, 2021;6(2):119-135.

3. Aarekar SA, Pawar RB, Kulkarni RV, Pharande AL. Effect of silicon on yield, nutrients uptake by paddy plant and soil properties. Journal of Agriculture Research and Technology. 2014;39(2):328-331.
4. Abou-Baker NH, Abd-Eladl M, Abbas MM. Use of silicate and different cultivation practices in alleviating salt stress effect on bean plants. Australian Journal of Basic and Applied Sciences. 2011;5(9):769-781.
5. Artyszak A. Effect of silicon fertilization on crop yield quantity and quality-A literature review in Europe. Plants. 2018;7(3):54.
6. Badran MA. Effect of spraying seaweed extracts and silicon yield and fruit quality of Zaghloul date palms grown under sandy soil condition. Assiut J. Agric. Sci. 2016;47(5):165-174.
7. Babini E, Marconi S, Cozzolino S, Ritota M, Taglienti A, Sequi P. Bio-available silicon fertilization effects on strawberry shelf-life. In XXVIII. 2012.
8. International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on Postharvest Technology in the Global Market (pp. 815-818).
9. Bhavya HK. Effect of foliar silicic acid and boron in Bangalore blue grapes (Doctoral dissertation, University of Agricultural Sciences, GKVK). 2010.
10. Costan A, Stamatakis A, Chrysargyris A, Petropoulos SA, Tzortzakis N. Interactive effects of salinity and silicon application on *Solanum lycopersicum* growth, physiology and shelf-life of fruit produced hydroponically. Journal of the Science of Food and Agriculture. 2020;100(2):732-743.
11. Chaudhary P, Kaushik RA, Rathore RS, Sharma M, Kaushik MK. Improving growth, yield and quality of kinnow mandarin through foliar application of potassium and zinc. Indian Journal of Horticulture. 2016;73(4):597-600.
12. Dhinesh Bau K, Dubey AK, Yadav DS. Effect of micronutrients on enhancing the productivity and quality of kinnow mandarin. Indian Journal of Horticulture. 2007;64(3):353-35.
13. Epstein E. The anomaly of silicon in plant biology. Proceedings of the National Academy of Sciences. 1994;91(1):11-17.
14. Epstein E. Silicon. Annual review of plant biology, 1999;50(1):641-664.
15. Ferreira HA, do Nascimento CWA, Datnoff LE, de Sousa Nunes GH, Preston W, de Souza EB. Effects of silicon on resistance to bacterial fruit blotch and growth of melon. Crop Protection. 2015;78:277-283.
16. Ferreira RLF, Souza RJD, Carvalho JGD, Araújo Neto SED, Mendonça V, Wadt PGS. Evaluation of lettuce cultivars fertilized with calcium silicate in the greenhouse. Ciência e Agrotecnologia. 2010;34(5):1093-1101.
17. Frantz JM, Locke JC, Sturtz DS, Leisner S. Silicon in ornamental crops: detection, delivery, and function. silício na agricultura. UFV, DPF, Viços. 2010, 111-134.
18. Guntzer F, Keller C, Meunier JD. Benefits of plant silicon for crops: a review. Agronomy for Sustainable Development. 2012;32(1):201-213.
19. Gillman JH, Zlesak DC, Smith JA. Applications of Potassium Silicate Decrease Black Spot Infection in Rosa hybridaMeipelta' (Fuschia Meidiland™). Hort Science, 2003;38(6):1144-1147.
20. Hanumanthaiah MR, Kulapatihipparagi RC, Renuka DM, Kiran Kumar K, Santhosha KV. Effect of soil and foliar application of silicon on fruit quality parameters of banana cv. Ney Poovan under hill zone. Plant Archives. 2015;15(1):221-224.
21. Hussien MA, Kassem MS. Influence of Spraying Kaolin, Silicon and Calcium on Productivity and Quality of Sultani Fig. Egyptian Journal of Horticulture. 2021;48(1):9-18.
22. Jamali B, Rahemi M. Carnation flowers senescence as influenced by nickel, cobalt and silicon. Journal of Biological and Environmental Sciences. 2011;5(15):147-152.
23. Jia JX, Cai DL, Liu ZM. New progress in silicon-improvement of quality of crops. Proceedings of the 5th International Conference on Silicon in Agriculture, 2011, 77.
24. Karagiannis E, Michailidis M, Skodra C, Molassiotis A, Tanou G. Silicon influenced ripening metabolism and improved fruit quality traits in apples. Plant Physiology and Biochemistry. 2021;166:270-277.
25. Kaluwa K, Bertling I, Bower JP, Tesfay SZ. Silicon application effects on 'Hass' avocado fruit physiology. South African Avocado Growers' Association Yearbook, 2010;33:44-47.
26. Kamenidou S, Cavins TJ, Marek S. Silicon supplements affect horticultural traits of greenhouse-produced ornamental sunflowers. Hort, Sci. 2008;43(1):236-239.
27. Kamenidou S, Cavins TJ, Marek S. Silicon supplements affect Floricultural quality traits and elemental nutrients concentrations of greenhouse Produced gerbera. Scientia Hort. 2010;123(3):390-394
28. Kanto T. Research of silicate for improvement of plant defense against pathogens in Japan. In Abstract of Second Silicon in Agriculture Conference, 2002.
29. Kumar JITENDRA, Kumar R, Rai R, Mishra DS. Response of 'Pant Prabhat'guava trees to foliar sprays of zinc, boron, calcium and potassium at different plant growth stages. The Bioscan. 2015;10(2):495-498.
30. Kumar S, Verma DK. Effect of micro-nutrients and NAA on yield and quality of litchi cv. Dehradun. Proceedings of International Sem. on Recent Trend in Hi- tech Horticulture and Post Harvest Tech. 2004, 193.
31. Lauwers AM, Heinen W. Bio-degradation and utilization of silica and quartz. Archives of Microbiology. 1974;95(1):67-78.
32. Laane HM. The effects of foliar sprays with different silicon compounds. Plants. 2018;7(2):45.
33. Lalithya KA, Bhagya HP, Choudhary R. Response of silicon and micro nutrients on fruit character and nutrient content in the leaf of sapota. Biolife. 2014;2(2):593-598.
34. Lalithya KA, Hipparagi K, Thippeshappa GN. Influence of silicon and micronutrients on yield and quality traits of sapota cv. Kalipatti under hill zone. Crop Research, 2013;46(1-3):150-152.
35. Li Z, Liu Z, Zhang M, Li C, Li YC, Wan Y. Long-term effects of controlled-release potassium chloride on soil available potassium, nutrient absorption and yield of maize plants. Soil and Tillage Research. 2020;196:104438.
36. Liang Y, Nikolic M, Bélanger R, Gong H, Song A. Silicon-mediated tolerance to salt stress. Silicon in

agriculture. 2015, 123-142.

37. Liang Y, Si J, Römheld V. Silicon uptake and transport is an active process in Cucumis sativus. New Phytologist, 2005;167(3):797-804.
38. Liang Y, Sun W, Zhu YG, Christie P. Mechanisms of Silicon-mediated alleviation of abiotic stresses in higher plants; A review. Environmental Pollution. 2007;147;422-428.
39. Lokesh Yadav, Varu DK. Effect of pre harvest spray and post-harvest dipping Fruit on shelf life and quality of papaya. Asian J Hort. 2013;8(2):581-587.
40. Ma JF, Yamaji N. Silicon uptake and accumulation in higher plants. Trends in plant science. 2006;11(8):392-397.
41. Mangali Mounika DT, Kumar AK, Joshi V, Sunil N. Studies on the effect of foliar application of calcium, potassium and silicon on quality and shelf life of sweet orange (*Citrus sinensis* L.) cv. Sathgudi. Journal of Pharmacognosy and Phytochemistry. 2021;10(1):1711-1713.
42. Meena VD, Dotaniya ML, Coumar V, Rajendiran S, Kundu S, Rao AS. A case for silicon fertilization to improve crop yields in tropical soils. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences. 2014;84(3):505-518.
43. Mounika T, Reddy NN, Lakshmi NJ, Joshi V. Studies on the effect of postharvest treatments on shelf life and quality of mango (*Mangifera indica*) cv. Amrapali. Journal of Applied and Natural Science. 2017;9(4):2055-2061.
44. Melo SPD, Korndörfer GH, Korndörfer CM, Lana RMQ, Santana DGD. Silicon accumulation and water deficit tolerance in Brachiaria grasses. Scientia Agricola. 2003;60(4):755-759.
45. Ma JF, Takahashi E. Soil, fertilizer, and plant silicon research in Japan. Elsevier. 2002, 45.
46. Ma JF, Miyake Y, Takahashi E. Silicon as a beneficial element for crop plants. Studies in plant Science. 2001;8:17-39.
47. Nada MM. Effect of foliar application with potassium silicate and glycine betaine on growth and early yield quality of strawberry plants. Journal of Plant Production. 2020;11(12):1295-1302.
48. Nikagolla NGDN, Udugala-Ganehenege MY, Daundasekera WAM. Postharvest application of potassium silicate improves keeping quality of banana. The Journal of Horticultural Science and Biotechnology. 2019;94(6):735-743.
49. Patel HA, Patel MJ, Vasara R, Patel NG, Sutariya NK. Effect of pre- harvest spray of calcium on biochemical parameters of sapota [*Manilkara achras* (Mill.) Forsberg] fruits cv. Kalipatti. Journal of Pharmacognosy and Phytochemistry. 2017;6(5):712-715.
50. Reddy SVR, Sharma RR. Effect of pre-harvest application of salicylic acid on the postharvest fruit quality of the Amrapali mango (*Mangifera indica*). Indian Journal of Agricultural Sciences. 2016;86(6):727-731.
51. Su XW, Wei SC, Jiang YM, Huang YY. Effects of silicon on quality of apple fruit and Mn content in plants on acid soils. Shandong Agric Sci. 2011;6:59-61.
52. Sommer M, Kaczorek D, Kuzyakov Y, Breuer J. Silicon pools and fluxes in soils and landscapes-a review. Journal of Plant Nutrition and Soil Science. 2006;169(3):310-329.
53. Thippeshappa GN, Ravi CS, Ramesha YS. Influence of soil and foliar application of silicon on vegetative characters, fruit yield and nutrients content of sapota leaf. Research on Crops. 2014;15(3):626-630.
54. Tesfay SZ, Bertling I, Bower JP. Effects of postharvest potassium silicate application on phenolics and other anti-oxidant systems aligned to avocado fruit quality. Postharvest Biology and Technology. 2011;60(2):92-99.
55. Vidya A, Swamy GSK, Prakash NB, Jagadeesh RC, Jagadesh SL, Gangadharappa PM. Effect of pre-harvest spray of nutrients on the physico-chemical characters in mango (*Mangifera indica* L.*)* cv. Mallika. Mysore Journal of Agriculture. Sciences. 2014;48(4):529-533.
56. Vijay V, Dalal RPS, Beniwal BS, Saini H. Impact of foliar application of potassium and its spray schedule on yield and quality of sweet orange (*Citrus sinensis*) cv. Jaffa. Journal of Applied and Natural Science. 2016;8(4):1893-1898.
57. Weerahewa HLD, David D. Effect of silicon and potassium on tomato anthracnose and on the postharvest quality of tomato fruit *(Lycopersicon esculentum Mill.).* 2015.
58. Watanabe T, Broadley MR, Jansen S, White PJ, Takada J, Satake K. Evolutionary control of leafelement composition in plants. New Phytologist. 2007;174(3):516-523.
59. Wu L, Liu M. Slow-release potassium silicate fertilizer with the function of superabsorbent and water retention. Industrial & engineering chemistry research. 2007;46(20):6494-6500.
60. Xiang Y, Ru X, Shi J, Song J, Zhao H, Liu Y. Preparation and properties of a novel semi-IPN slow-release fertilizer with the function of water retention. Journal of agricultural and food chemistry. 2017;65(50):10851-10858.