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SIGNIFICANCE OF SILICON IN FRUIT CROPS - A REVIEW

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Abstract

Silicon is the second most abundant element in the soil next to oxygen. However, still it is not recognized as an essential element for plant growth but the undeniable beneficial effects of this element on the growth and development have been observed in a wide variety of plant species. The role of silicon in plant biology is to reduce multiple stresses including biotic and abiotic stresses. In addition to naturally occurring soluble silicon in soil, many crops respond positively to additions of supplemental silicon. Plants, especially fruit crops, can take up large amounts of silicon where it contributes to their mechanical strength. Besides a structural role, silicon helps to protect plants from insect attack, disease and environmental stress. In the context of organic farming, the application of silicon sources to fruit crops may pave way for increasing the yield and reducing the use of chemical fertilizers, pesticides and fungicides.

Key words : Beneficial effect, biotic and abiotic stress, fruit crops, silicon, yield.

Introduction

Silicon is the second most abundant element in the soil next to oxygen and comprises 28 % of its weight (Epstein, 1999). Soils generally contain from 50 to 400 g Si kg^{-1}. The silicon content in the soil depends on the soil type and varies from 200 to 350 g of Si kg^{-1} of soil in clay soils while in the sandy soil from 450 to 480 g Si kg^{-1} of soil (Kovda, 1973). Warm, moderately humid tropical climates with highly weathered soils generally have less Si in their soils due to desilication. While most temperate soils will contain adequate Si, repeated cropping can significantly reduce plant available Si over time, especially in high Si uptake crops (Datnoff and Rodrigues, 2005). The inert quartz or crystalline silicates are the main Si-rich compounds forming the skeleton of the soil. The physically and chemically active Si substances in the soil are represented by soluble monosilicic acids, polysilicic acids and organosilicon compounds (Matichenkov and Ammosova, 1996). The soluble monosilicic acids are absorbed by plants and microorganisms (Yoshida, 1975). Typical concentrations of silicic acid in soil solution range from 0.1 to 0.6 mM. They also control chemical and biological properties of the soil P, Al, Fe, Mn and heavy metal mobility, microbial activity, stability of soil organic matter and formation of polysilicic acids and secondary minerals in the soil (Matichenkov *et al*., 2000; Sokolova, 1985). Polysilicic acid has a significant effect on soil texture, water holding capacity, adsorption capacity and stability of soil erosion (Matichenkov *et al*., 2000).

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Silicon uptake and accumulation in plants

Although abundant, silicon is never found in a plant available form and is always combined with other elements, usually forming oxides or silicates (Gunes *et al*., 2007). Silicon is absorbed by plants in the form of uncharged silicic acid (H4SiO4) and is ultimately irreversibly precipitated throughout the plant as amorphous silica (Ranganathan *et al*., 2006). Si is taken up by the root in the form of silicic acid and then translocated to the shoot in the same form. In the shoot, Si is polymerized into silica and deposited in the bulliform cells (silica body) and under the cuticle. The transport of Si from cortical cells to the xylem (xylem loading) the Si concentration in the xylem sap is much higher in rice than it is in other low-Si accumulating plants. In rice, Xylem loading is mediated by a transporter, while low-Si accumulating plants use diffusion. The distribution of Si in the shoot is controlled by transpiration. More Si accumulates in older tissues because this element is not mobile within the plants. Silicon is deposited as a 2.5 mm layer in the space immediately beneath the thin (0.1 mm) cuticle layer, forming a cuticle–Si double layer in leaf blades. The wide variation in Si concentration in plant species is attributed mainly to differences in the characteristics of Si-uptake and transport. Many plants can accumulate Si concentrations higher than essential macronutrients (Epstein, 1999). Active Si-uptake has been demonstrated in Graminaceous species such as rice (Ma *et al*., 2001), wheat (Rains *et al*., 2006), ryegrass (Jarvis, 1987) and barley (Barber and Shone, 1966). However, some Gramineae plants such as oats take up Si passively (Jones and Handreck, 1967). Passive Si-uptake has been demonstrated in some dicots such as cucumber, melon, strawberry and soyabean (Liang *et al*., 2005). Unfortunately, molecular mechanisms underlying Si uptake in these plants are unknown (Ma and Yamaji, 2006).

However, Si still is not recognized as an essential element for plant growth but the undeniable beneficial effects of this element on the growth, development, yield and disease resistance have been observed in a wide variety of plant species. The role of silicon in plant biology is to reduce multiple stresses including biotic and abiotic stresses. It is also known to increase drought tolerance in plants by maintaining plant water balance, erectness of leaves and structure of xylem vessels under high transpiration rates (Melo *et al*., 2003). Gong *et al*. (2006) observed improved water economy and dry matter yield by silicon application and it enhanced leaf water potential under water stress conditions, reduced incidence of micronutrient and metal toxicity (Matoh *et al*., 1991).

In addition to naturally occurring soluble Si in soil, many crops respond positively to additions of supplemental Si. Plants, especially grasses, can take up large amounts of Si where it contributes to their mechanical strength. Besides a structural role, Si helps to protect plants from insect attack, disease and environmental stress. For some crops, Si fertilization of soils increases crop yield even under favourable growing conditions and in the absence of disease. A second mechanism for the beneficial effects of Si is its role in triggering a range of natural defences. For example, the presence of Si has been shown to stimulate activity of active compounds such as chitinase, peroxidase, polyphenol oxidases and flavonoid phytoalexins–all of which can protect against fungal pathogens.

Banana

Banana is perennial giant herb. Banana production plays a major role in food security for more than 400 million people in developing countries in tropical areas and is a source of income and employment for local populations (Arias *et al*., 2003). Bananas for export are cultivated in perennial intensive monocultures, and are therefore hampered by many recurrent pests and diseases. In banana plantations, soilborne pathogens are major constraints limiting crop production. *Cylindrocladium spathiphylli* has been identified as the most pathogenic root-rot fungi species within the Cylindrocladium genus for the banana rhizosphere cause necrotic root and corm lesions that lead to nutrient uptake reduction, root breakage and toppling of banana plants (Risede, 2008). Vermeire *et al*. (2011) conducted an experiment on protective role of silicon in the banana-*Cylindrocladium spathiphylli* pathosystem. And they reported that silicon application had a protective role in banana against root rot fungus (*Cylindrocladium spathiphylli*) and plants amended with 2 mM Si exhibited a reduction of about 50 % in the necrosis percentage of inoculated roots at 14 days after inoculation compared with plants grown without application of Si. Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *cubense*, is one of the most important diseases affecting banana production worldwide. After *F. Oxysporum* f. sp. *cubense* establishes itself in the soil, the fungus is difficult to eradicate, and the existence of several races of *F. oxysporum* f. sp. *cubense* makes the use of resistant cultivars very difficult (Ploetz and Pegg, 2000). In this view, Fortunato *et al*. (2012) studied the physiological and biochemical aspects of the resistance of banana plants to fusarium wilt potentiated by silicon and reported that Si has a great potential for reducing the intensity of fusarium wilt concomitantly with more concentrations of hydrogen peroxide (H_2O_2), total soluble phenolics (TSP) and lignin-thioglycolic acid (LTGA) derivatives and greater activities of phenylalanine ammonialyases (PALs), polyphenoloxidases (PPOs), peroxidises (POXs), β-1,3-glucanases (GLUs) and chitinases (CHIs). A field experiment was conducted by Hanumanthaiah *et al.* (2015) at College of Horticulture, Mudigere (Karnataka), India to know the effect of soil and foliar application of silicon on fruit quality of banana cv. Neypoovan. Results revealed that foliar application of Si @ 4ml and 2ml/l/ plant at 15 days interval proved to be better in improving the quality parameters in banana like shelf life (6.33 days), TSS (26.67 ^{0}Brix), pulp/peel ratio (7.44), acidity (0.26 %), reducing sugars (19.93 %) and non reducing sugars (2.24 %). Influence of diatomaceous earth on yield with its attributing characters and quality of banana in the northern zone of the Karnataka was studied by Kumbargire *et al*. (2015) at KRC college of horticulture, Arabhavi (Karnataka), India and reported that application of diatomaceous earth (DE) as a source of silicon @ 750 kg/ha + RDF for banana showed positive effect on bunch characters, finger characters and quality parameters. They also noted minimum white fly infestation (15.41%) and sigatoka leaf spot infestation (28.67%) in the same treatment. Kumbargire *et al*. (2016) noticed maximum composition of macronutrient like N (3.48%), P (0.37%), K (4.23%), Ca (0.75%) and Mg (0.35%) as well as micronutrient like Zn (27 ppm) and Cu (12.37 ppm) in banana leaf in RDF+750 kg/ha of DE, which indirectly reflects on the growth, development and yield of banana.

Sapota

A field experiment was conducted by Lalithya *et al*. (2013) at 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 tree sprayed with K_2SiO_3 @ 8 ml/l was found better in improving number of shoots (23.96/m^2), total chlorophyll content (8.47 mg/g of fresh weight), number of flowers (250.16/m^2) and also minimized number of mummified fruits (34/tree). The experiment, response of silicon and micro nutrients on fruit character and nutrient content in leaf of sapota carried out by Lalithya *et al*. (2014) at College of Horticulture, Mudigere (Karnataka), it was observed that foliar application of K_2SiO_3 @ 8ml/l helped in improving the fruit characters like fruit weight (99.96 g), fruit length (5.55 cm), fruit diameter (5.85 cm), volume of fruit (102.38 g) maximum shelf life (10.90 days) and yield (12.48 t/ha) of sapota. However, soil application of $CaSiO_3$ @ 2.5 kg/tree resulted in highest B:C ratio (2.36).

Mango

Mango (*Mangifera indica* L.) belongs to family Anacardiaceae and has been called, in the orient, “King of the fruits”. Mango is rightly known as ‘National Fruit of India’, owing to its nutritional richness, unique taste and flavour, religious and medicinal importance. It is the third widely produced fruit crop of the tropics after banana and citrus. It is originated from South East Asia, the Indo-Burma region, in the foothills of the Himalayas (Mukherjee, 1951). To evaluate the influence of different silicon quantities applied to the soil on ‘Palmer’ mango tree cultivation under irrigated conditions, an experiment was performed at a commercial ‘Palmer’ mango orchard in Matias Cardoso, MG, Brazil by Costa *et al*. (2015). Results revealed that different quantities of Agro-silicon soil applications did not influence the disease or pest incidence or the silicon, calcium and magnesium content of ‘Palmer’ mango-associated soil and leaves but there was a quadratic increase in the diameter of the fruit, in which the largest diameter was associated with 1600 kg/ha of Agro-silicon. El-deen *et al*. (2015) studied the soil mulching and foliar anti-transpirations effect on soil, growth and nutrients status of young mango trees at Toshki Research Station, Desert Research Center, Aswan Governorate, Egypt. Results indicated that, both soil mulching and anti-transpiration materials enhanced and increased growth parameters, leaf nutrient contents and some soil physical and chemical properties. Separately mulching with compost or spraying with kaolin @ 6% (once in a month from April to August) showed significant superiority over mulching and spraying treatments. The interaction between mulching with compost + spraying with kaolin showed the significant effect on improving and increasing all the studied parameters of young mango trees as well as soil properties. From the research result of More *et al*. (2015) on 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 at College of Agriculture, Dapoli (Maharashtra), it was observed that application of stabilized silicic acid *i.e.* silixol @ 1.5 ml/l with five sprays during initial stages of fruit growth (before flowering and 15, 30, 45 and 60 DAF) was found to be good in improving the yield and quality of mango cv. ‘Alphonso’.

Pomegranate

Pomegranate is one of the oldest known edible fruits cultivated extensively in Mediterranean conditions. Pomegranates are sold as whole fruits, but exposure of the fruit to intense sunlight can cause sunburn damage in the form of large black spots on the fruit skin, which render the fruit unmarketable. Pomegranates are especially sensitive to sun because they are terminal-bearing plants, with generally thin branches that bend with the increase in fruit weight as the season progresses. It is a known fact that some fruits crack during the latter period of growth. It may be due to moisture imbalances as this fruit is very sensitive to variation in soil moisture prolonged drought causes hardening of peel and if this is followed by heavy irrigation the pulp grows then peel grows and cracks. Cracking causes a major fruits loss, which is a serious commercial loss to farmers. Fruit cracking, seems to be a problem that lessens the marketability to a great extent. Several approaches could be taken to reduce fruit cracking and sunburn damage. Melgarejo *et al*. (2004) reported that four sprays of kaolin, 1st @ 5% (2nd week of June) 2nd, 3rd and 4th @ 2.5% (2 weeks interval) to pomegranate plant resulted in maximum premium quality fruits (90.6%) and minimum unmarketable fruits (9.4%) than control. A study was carried out in order to determine effects of kaolin and shading treatments on sunburn in pomegranate cv. Hicaznar by Yazici and Kaynak (2006) at Batý Akdeniz

Agricultural Research Institute, Antalya, Turkey. They found that plants covered with 35% shading materials with the foliar applications of kaolin @ 3% on July 30, August 6, August 13 and August 20 were more effective to decreased sunburn damage in pomegranate cv. ‘Hicaznar’ compared to shading treatment alone. And in another experiment carried out by El-Rhman (2010) at Desert Research Center. Min. of Agric. and land Reclamation, Egypt it was observed that pomegranate plants irrigated at every two days and foliar application of kaolin @ 6%, reduced fruit cracking (27.98%), increased fruits per plant (57.53), fruit weight (418.5 g), yield (23.98 kg/plant), pulp (60.69%), total sugars (13.03%) and reducing sugars (12.02%).

Citrus

Although, the mysteries of its history and origin remain unsolved, worldwide cultivation and high-demand production for citrus fruit make it stand high among fruit crops. Characterized by the distinct aroma and delicious taste, citrus fruits have been recognized as an important food and integrated as part of our daily diet, playing key roles in supplying energy and nutrients and in health promotion. With low protein and very little fat content, citrus fruits supply mainly carbohydrates, such as sucrose, glucose and fructose. Fresh citrus fruits are also a good source of dietary fiber, which is associated with gastrointestinal disease prevention and lowered circulating cholesterol. Is one of the world’s major fruit crops with global availability and popularity contributing to human diets. Due to unclear numbers of natural species and wide areas for cultivation, the most well-known examples of citrus fruits with commercial importance are oranges, lemons, limes, grapefruit and tangerines. Matichenkov *et al*. (1999) conducted an experiment at Indian River Research and Education Center, University of Florida, Fort Pierce to determine the direct effect of silicon-containing compounds on citrus grown on sandy soils and concluded that silicon may play a very important role in citrus tree growth and development. Si in citrus leaves increased with age and biotic stress. The monosilicic acid increased the weight of shoots and roots of grapefruit seedlings from 20 to 60% and improved root system branching. And again Matichenkov *et al.* (2001) studied the response of citrus to silicon soil amendments under various stress conditions and revealed that maximum weight of seedling was noted under salt stress and low temperature for Pro-Sil @ 2 and 8 t/ha (without macronutrient) respectively, while under Al toxicity Pro-Sil @ 8 t/ha with macronutrient registered maximum seedling weight. And increased tree height from 14 to 41 % and accelerated growth of the tree branches from 31 to 48% over a 6-month period were recorded by the application of Pro-Sil in sweet orange cv. ‘Valencia’. The citrus blackfly (*Aleurocanthus woglumi*), is a pest that affects approximately 300 species of host plants. *A. woglumi* is native to Asia and is considered a pest of great importance in several countries due to crop damage or loss, which reduces the quality and/or quantity of production in a large number of crops. In this view, Vieria *et al*. (2016) carried out an experiment to evaluate the effects of silicon dose on the activity of the enzymes peroxidase, polyphenol oxidase and phenylalanine ammonialyase (PAL), known to be involved in the defence system of *Citrus reticulata* to *A. woglumi*. Results revealed that Potassium silicate is an elicitor that potentiates the defence mechanisms of *C. reticulate* against *A. woglumi*. The increase in peroxidase and polyphenoloxidase activities revealed the induction of compound synthesis for plant defence against *A. woglumi*, but this effect was dependent on the time of *A. woglumi* feeding and on the concentration of silicon.

Grape

The grapes commonly known as grapevine (*Vitis vinifera* L.) bleongs to the family Vitaceae and it is a historically important fruit plant. Traditionally, grape has been used as important source of medicine as well as nutritions. In grape culture, powdery mildew caused- by *Uncinula necator* is one of the most common and difficult-to-control diseases. Bowen *et al*. (1992) conducted an experiment to determine the effect of foliar spray of water, Si and K_2HPO_4 on severity of powdery mildew [*Uncinula necator* (Schwein) Burrill] in grape at Agriculture Research Station, Canada. The results showed that minimum numbers of colonies were developed in treatment of Si @ 17 mM at 13, 16 and 19 days after inoculation and they also noted that there were no differences in the number of *U. necator* colonies that developed on water-sprayed and K_2HPO_4-sprayed leaves so the severity of *U. necator* infection is unaffected by K and PO_4 together on the leaf surface but is reduced by the presence of Si.

Avocado

The avocado (*Persea americana*) is a native of Central America and the West Indies belongs to the family Lauraceae. Avocado is an energetic fruit with high nutritional value and is considered a major tropical fruit, since it is rich in protein and contains fat soluble vitamins lacking in other fruits, including Vitamins A and B, and median levels of vitamins D and E. It contains different oil levels in the pulp, thus it is widely used in pharmaceutical and cosmetic industries. Good phytosanitary measures are a requirement for export and are needed in ensuring high product quality. This is particularly important in avocado as the fruit is a perishable product (Wills *et al*., 1989) with a relatively high respiration rate, resulting in a quick deterioration of fruit quality. Additionally, due to the threat of pest and disease resistance to currently used chemicals, a great need exists to diversify from their usage. Kaluwa *et al*. (2010) studied the silicon application effects on 'Hass' avocado fruit physiology at Horticultural Science, University of KwaZulu-Natal, South Africa and concluded that post-harvest application of 2940 ppm Si in the form of K_2SiO_3 to avocado fruits seem to be most beneficial in suppressing ethylene production and thereby enhanced shelf life. In another experiment on effects of postharvest potassium silicate application on phenolics and other anti-oxidant systems aligned to avocado fruit quality conducted by Tesfay *et al*. (2011) it was observed that fruit firmness, weight loss, mesocarp electrical conductivity (EC), total phenolics concentration, lipid peroxidation as well as polyphenol oxidase and catalase activity responded positively to the KSil treatments. Therefore, Si applications could be used to increase the pool of free phenols in the mesocarp, thereby increasing fruit quality.

Conclusion

The role of silicon as a nutrient for plant growth was overlooked because of its natural abundance. But with the application of more nitrogenous fertilizers, crops become succulent, prone to lodging and increased incidence of pests and diseases resulting in demand for more silicon than the soil could sustain.

Silicon nutrition enhances host resistance to pests and diseases and also alleviates abiotic stresses thus protecting the crops. In the context of organic farming the application of siliceous materials and silicon sources to not only agricultural crops but also to horticultural crops especially fruit crops may pave way for increasing the yield and reducing the use of chemical fertilizers, pesticides and fungicides. The ashes from agro industries and industrial slags free from heavy metals will find future source of silicon fertilizers in future to protect the crops and to boost the yield.

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