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ROLE OF BIOLOGICAL SILICA IN ENHANCEMENT OF AGRICULTURAL PRODUCTIVITY : A REVIEW

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ABSTRACT

Silicon is the second most abundant element in the earth's crust, and hence is plentiful in most soils. Silica is absorbed by plants as silicic acid, with cereals and grasses containing the highest concentrations (0.2-2.0%). Most soils contain significant quantities of silica, but continuous cropping, particularly with crops that accumulate significant quantities of silica, can reduce plant available levels of Si to the point that supplemental Si fertilization is required. There appears to be a need for Si amendments in temperate as well as tropical crop production systems, and Si fertilizers are applied to crops in several countries for increased productivity and sustainable production. High silica uptake has been shown to improve drought resistance, increase resistance to fungi and other pathogens, and increase plant growth rate and yield. However, its essentiality as a micronutrient for higher plants is difficult to prove, partly due to the fact that many positive effects of Si are most apparent in cases of abiotic stresses. Silica amendments have also been shown to correct soil toxicities resulting from high levels of soluble Mn^{2+}, Fe^{2+}, and Al^{3+}. Most plants groups are known to deposit silica between the cells and tissues in solid form creating amorphous structures called Phytoliths or Silica bodies. Phytoliths are formed after absorbing silica in soluble form, as is offered in Biological silica. They provide mechanical strength and rigidity to plant parts and act as defence system against insects, pests and fungal infestations as well as improve water balance, plant growth and yield, rates of photosynthesis and reproduction. Silica acts as immune-stimulator within crops thus enable the enhancement of defence mechanism in crops. Silica enables the plants build up a physical mineral barrier lining the cell. This makes it difficult for biting and sucking bugs to damage the plants. Naturally this reduces the food intake, growth longevity and population growth ofxylem feeding insects and other pathogens. It has been observed that plants accumulate Silica around fungal infected sites. If the plant has sufficient silica level, it creates an active defence against fungal infections as well. From last few decade silicon is getting great attention due to its abundance and non-hazardous nature. Silicon nutrition is found to be very helpful providing resistance to crops against biotic and abiotic stresses. Silicon also provide resistance to the plants against pathogens. The present review is thus attempted to define nature of silica, its compatibility with crops and applications of silica in enhancement of agricultural productivity in terms of sustainable agriculture.

***Keywords*:** Biological silica, phytoliths, resistance against biotic and abiotic stresses, immune-stimulator of crops, pesticidal and antifungal agent.

Introduction

The word silicon is derived from the Latin word silex, meaning flint. The word was originally used to denote any hard rock. In modern English, silicon refers to the element and silica refers to a compound in which each molecule of silicon is chemically bound to two oxygen molecules (SiO_2; silicon dioxide). The earth's crust contains a large proportion of silicon. This silicon is mostly in the form of silicates and aluminosilicates. In soil solutions, silicon is found mostly in the form of silicic acid Si(OH)4 (Lindsay, 1979; Epstein, 1994). In plants, silicon is found mostly as silicon dioxide. Although silicon can be found in great abundance on this planet, its biological functions are not as well studied as those of other elements such as oxygen, hydrogen and carbon (Wainwright, 1997). Silicon is considered an essential nutrient for a group of algae known as diatoms (Round *et al*., 1990; Kinrade *et al*., 2001). As for vascular plants, silicon is only considered essential for the Equisetaceae family (Chen and Lewin, 1969). However, silicon is absorbed by mostplants, in greater or lesser quantities (Epstein and Bloom 2005). In particular, gramineous crops are known to absorb silicon in higher amounts (Rafi and Epstein, 1999; Tamai and Ma, 2003). The interactions of silicon with crop plants have been of particular interest (Ma and Takahashi, 2002; Tamai and Ma, 2003; Rodrigues *et al*., 2004). Silicon (Si) is a broadly recognized beneficial and essential for animal and human beings, but not essential element for higher plants(Epstein 1994; Liang *et al*., 2015). However the essentiality of Si for plant has not been yet proved but it has beneficial effects in promoting plant growth in stressful conditions has been proved in both laboratory experimentation or field trails (Ma 2004; Liang *et al.,* 2007; Guntzer *et al*., 2012; Wang *et al.,*2017), AAPFCO consider silicon to be "beneficial substance" defined as: "Any substance other than primary, secondary and micro plant nutrients that can be demonstrated by scientific research to be beneficial to one or more species of plant, when applied to the plant or soil". Recent studies and significant resources support that Si plays essential role in plant metabolism. This would affect label claims for Si products that Si is an essential nutrient for plant growth (McGinnity, 2015)

Occurrence of Silicon in plants

The occurrence of silicon in the plants depends on the species(Epstein 1999), the plants belongs to Gramineae family had higher Si concentration. Ma and Takahashi (2002) reported that unlike other elements. Si is abundant in almost all types of soil, so environmental conditions does not have impact of Si accumulation in plants. They also developed the phylogenetic tree and noticed that Si-rich species have low calcium concentration whereas Si–low species have high calcium concentration. They proposed the model which is given below:

- Plants have Si concentration over 1% and Si/Ca ratio>1 are denoted as "Si- Accumulators"
- Plants have Si concentration below 0.5% and Si/Ca ratio<0.5 are denoted as "Si – Excluders"
- Plants which are not in both the category are denoted as "Si-intermediates"

Si in Soil

From the report of Sharma (2016) Silicon is found 28,20% in the earth crust. It is the second most abundant biomolecule after oxygen. Silicon is an organic dynamic component which helps in activating natural defence mechanism in rice crop (Currie and Perry, 2007)

Root Uptake

Mostly the Silicon exist in insoluble crystalline aluminosilicates form in the soil, which are not directly up taken by plants (Richmond and Sussman 2003; Liang *et al*., 2015). For the uptake of Silicon by plant root the pH range between 2-9 as recommended by Knight and Kinrade, 2001 and the monosilic acid soluble form of Si in soil (Figure1) can be taken up by the roots of plants (Richmond and Sussman 2003; Liang *et al*., 2015)

Plants take Silicon in the orthosilicic acid (H_4SiO_4), which is molecule which can cross plant root plasma membrane at physiological pH ranges (Epstein 1994; Raven 2003). Due the difference in the plant ability to accumulate Si. Ma *et al*. (2001 a) also states that the uptake of Si occurs only in the lateral roots but not involve the root hairs. Si transport mechanism was demonstrated in rice and corn (Mitali *et al*., 2009).

Active and Passive uptake mechanism also involved in the uptake of Si in the plants(Mitani and Ma 2005; Ding *et al*., 2008; Liang *et al*., 2007). Banana grown hydroponically in the solution with high Si-concentration uptake was proportional to the mass flow-driven supply. At low Si concentrations, Si absorption was greater than expected with a mass flow-driven supply suggesting an active uptake mechanism.

Transport and Distribution of Silicon in Plant body:

Takahashi *et al.* (1990) studies three different possible uptake of Silicon with respect to water in higher plants species.

- **Active–**Si uptake is higher than water uptake ,this system would cause Si depletion in the nutrient solution.
- **Passive-** Si uptake is similar speed as the water uptake speed, Si concentration remain constant in the nutrient solution.
- **Rejective-**Si uptake is slower or lower than water uptake, thus Si concentration tend to increase in the nutrient solution.

Most of the monocots uptake Silicon by active process, examples are given below:

Crop	Uptake of Silicon (Reported by)
Rice (Oryza *sativa)*	Takahashi *et al*., 1990; Tamai and Ma 2003
Wheat (*Triticum aestivum*)	Jarvis, 1987; Rains *et al*., 2006
Ryegrass (*Lolium perenne)*	Jarvis 1987; Nanayakkara *et al*., 2008
Barley (*Hordeum vulgare)*	Nikolic *et al*., 2007
Maize (*Zea mays)*	Laing *et al*., 2006

In dicots like sunflower (*Helianthus annuus* L.), wax gourd (*Benincasa hispida* L.)cucumber (Cucumis *sativus)*Silicon is transported by active process. On the contrary, most dicots take up Silicon by passive process. However, some dicots such as faba bean (*Vicia* faba*)* and tomato (*Lycopersicon esculentum)* found to exclude Silicon from their roots (Takahashi *et al*., 1990). Si further moves to the shoots by the transpiration process (Leng *et al*., 2009).Rice Lsi1(OsLsi1) was the first gene identified which is responsible for Si influx from external solution into root cells in rice (Ma *et al*., 2002). The gene OsLsi2 was isolated which is encoded for Si efflux transporter. The genes, Lsi1 and Lsi2 were isolated in barley (Chiba *et al*., 2009), ZmLsi1 and ZmLsi2 in maize (Mitali *et al*., 2009 a) and GmNIP2-1, GmNIP2-2 in soyabean (Deshmukh *et al*., 2013), CSiT1, CSiT2, CsLsi1 in Cucumber (Wang *et al*., 2015; Sun *et al*., 2017)

Benefials Effects of Silicon:-

(A) Silicon in Abiotic Stress:

a) Drought Stress

b) Salinity Stress

c) Excess Metals

d) Nutrient Regulation

e) Low Temperature Stress

f) Ultraviolet-B Radiation Stress

(B) Silicon in Biotic Stress:

(i) Bacterial Disease

(ii) Fungal Disease

(iii) Insect and Pest attack

(A) Silicon in Abiotic Stress:

a) Silicon on Drought Stress:

Drought Stress is an important concern because of its adverse impact on crop production. Silicon application gives significance positive impact on the plants ability to tolerate droughts stress (Eneji *et al.,* 2008). Accumulation of silicon in the plant tissues help to decrease the transpiration and improve light interception by keeping the leaf blade erect in position (Epstein, 1999).Wheat plant (treated with Silicon fertilizer) shows greater stomatal conductance,relative water content, and water potential than un-treated plant. Treated leaves were larger and thicker, reducing water loss through transpiration (Gong *et al*., 2003; Hattori *et al.,* 2005) and also reduce water use efficiency. Silicon increases resistance in rice in rice (Ma *et al*., 2001b), it is also found that silicon fertilizers enhance the development of secondary and tertiary cells of the endodermis which help in developing root resistance in dry soils and faster root growth (Bouzoubaa, 1991; Hattori *et al*., 2005). Silicon fertilizer also increase frost tolerance capacity in lemon and sugarcane (Matichenkov and Calvert, 2002). Silicon is meant for reducing drought stress by different other methods like increase in nutrient uptake in grass (Eneji *et al*., 2008), modification of gas exchange attributes, reduction in oxidation stress, osmotic adjustment, regulation of compatible solutes and modification in gene expression and phytohormone synthesis (Rizwan *et al.,* 2015).

b) Silicon on Salt Stress:

High salt concentrations normally give rise to impair the cellular electron transport within the different subcellular compartment and lead to generation of reactive oxygen species (ROS), which triggers phytotoxic reactions like DNA mutation, protein degradation and lipid peroxidation (Ali and Alqurainy, 2006). Addition of Silicon decreased permeability of the plasma membrane of leaf cells and improved the ultra-structure of chloroplast, which were badly damaged by NaCl addition with the double membranes disappearing and the grana being disintegrated in the absence of Silicon (Liang *et al.,* 2003). It has been emphasized in many review and research articles that water status of leaf and water-use efficiency of crops are increased by silicon application in many salt-stressed plants. Studies also reported that silicon may alleviate salt stress by inhibition of transport of sodium ions to the leaves and specific accumulation of these ions in the roots. It suffers salinity stress in tomato seedlings by increasing photosynthesis, stomatal conductance and leaf transpiration rate by decreasing Na^+ and Cl^+ concentration in the leaves, stem and roots (Li *et al.,* 2015).

c) Silicon on Excess Metal: -

Use of excessive acid fertilizers give rise to soil acidification, which result in decrease soil pH and fertility. Every metal interact with each plant with different and specific way due to different type of soil growth conditions and the presence of other ions (Rana and Masood, 2002). Silicon fertilizers are slightly basic in nature thus able to reduce the acidification of soil. Silicon increase metal binding capacity to the cell walls which limits cytoplasmic concentration of the heavy metals such as copper (Cu), cadmium (Cd), manganese (Mn) and zinc (Zn) (Liang *et al*., 2007). Silicon also reduces the concentration of phytotoxic aluminium in soil solution by forming sub colloidal and inert alumino-silicates with the interaction of silicon and aluminium (Al) (Liang *et al.,* 2007). There are number of studies which prove that Silicon reduce the toxic symptoms, especially for the metal which cause serious concern such as cadmium (Cd) (Sarwar *et al*., 2010). Shi *et al* (2005) studied on cucumber and reported the Manganese (Mn)toxicity is reduced by Silicon was attributed by significant reduction in lipid peroxidation (LPO)intensity caused by excess Manganese and increase in enzymatic activity like SOD, APX and GR.These activities (SOD, CAT and APX of barley was higher in plants growing with Silicon as compared to the plants without silicon (Gunes *et al*., 2007)

d) Silicon on Nutrient Regulation: -

Mali and Aert (2008a) have shown the effects of Silicon on potassium uptake in soil and hydroponics and stated that even if the concentration of Silicon was less in soil, but the uptake of Potassium (K) increases.They also reported that an increase in absorption of N and Ca (wheat) fertilized with increase of sodium metasilicate and also improvement in nodulation and N2 fixation in cowpea. The decreased erectness of rice leaves following by excess of N application can be reduced by the application of Silicon as a part of nutrient solution (Yoshida *et al*., 1969). Benchley and Maskell (1927) shown the effect of silicon on the availability of phosphorus in the soil. The researchers found that silicon increases the yield of barley crop even when the phosphorus fertilization was limited. It was observed that soil phosphorus was more available to plants when treated with silicon.

e) Silicon in Low Temperature Stress: -

Many studies proved that Silicon can enhance plant growth under freezing condition. Studies conducted in wheat plant showed that major anti-oxidant enzyme activities and non-enzymatic anti-oxidants (i.e. ascorbic acid and glutathione) in the leaf of freezing stressed plants decreased,but were stimulated by the exogenous application of Silicon. The mechanism for Si enhanced freezing stress may be due to higher anti-oxidant defence activity and lower lipid peroxidation by water retention in leaf tissues.Mechanism have been proposed based on the biochemical and physiological changes related to freezing injury(Mc Kersie 1991).

f) Silicon on Ultraviolet-B radiation stress

Rising solar Ultra-violet-B levels resulting from anthropogenic thinning of the stratospheric ozone layer, attracting the attention of environmentalists and governments all over the world. Ultra-violet-B stress also have the ability to deleterious the agricultural production (Hideg *et al*., 2013) Silicon play an important role in preventing the plant by filtering the devastating UV rays. It has been seen in sugarcane,that Silicon may protect leaves from ultraviolet radiation damage by filtering out harmful ultraviolet rays. UV-B radiation damage plant cells causing generation of ROS such as superoxide anions (O2), hydroxyl radicals (OH), hydrogen peroxide (H_2O_2) and singlet oxygen (O2) (Beckmann *et al*., 2012; Lizana *et al*., 2009; Zancan *et al*., 2008). Shen *et al.* (2010) reported that UV-B radiation stresses caused intensification of LPO (Lipid Peroxidation) in soyabean seedlings, but silicon application reduced the membrane damage. Fang *et al.*, 2011 also give the same report that silicon increases plant tolerance to UV-B radiation.

(B) Silicon on Biotic Stress:

(i) Bacterial Disease

Silicon plays an important role in inducing resistance against bacterial diseases. It performs signalling network by roots and can induce systematic resistance in other organs (Fawe *et al.,* 2001 and Silva *et al.,* 2010). This can be done by strengthening cell wall structures, activating specific mechanisms like phytoalexins production, pathogen related protein synthesis, increasing lignification etc (Cherif *et al*., 1994; Fawe *et al*., 2001; Manzies *et al.,*1991 and Silva *et al.,* 2010). Conceicao *et al*., 2014 demonstrated the silicon application on bacterial disease by spraying potassium silicate alone or in combination with the yeast *Rhodotorula aurantiaca* LMA1, which increases the activity of polyphenol oxidase and ascorbate peroxidase in melon respectively. Diongo and Wydra (2007) also studied the positive effects of silicon on tomato plant's bacterial disease. Silicon induce basal defence but it also induces a priming effect changes in the expression of defence genes were observed after challenging the Silicon treated plants with *Ralstonia solanacearum* (Ghareeb *et al*., 2011).

(ii) Fungal Disease

Silicon act as a mechanical barrier to protect the plant from invading pathogen, either by reducing the rate of progress of disease or by restricting the lesion size and production of spores dor secondary infection (Sebold *et al*., 2001). Silicon also enhance the level of preformed inhibitors like phenolics thus induce host resistance or by mediating the synthesis of post inflectionally formed antifungal phytoalexins or by activating oxidative enzymes (Fautex *et al*., 2005). The application of silicon (1000kg/ha) through calcium silicate help in reducing neck blast by 30.5% and brown spot by 15 % comparison to control (Datnoff and Rodrigues, 2005). It was also found to suppress ring spot in sugarcane, root rot and powdery mildews in cucumber (Menzies *et al*., 1991)Silicon application also suppress the leaf and neck blast, brown spot, sheath blight, leaf scald, stem rot and bacterial leaf blight infection in rice (Winslow 1992; Datnoff and Rodrigues 2005; Gangopadhyay and Chattopadhyay, 1975).

(iii) Insect and Pest attack

Datnoff *et al*., 1997 reported that the silicon application for pest management can save the cost of chemicals insecticides and fungicides. It has been noticed that sucking pests and leaf eating caterpillars have a low silica containing succulent parts. Salim and Saxena (1992) reported that, Silicon reduces the food intake, growth longevity, fecundity and population growth of xylem feeding by white backed plant hopper, *Sogatella frucifera.* Silicon in soluble form decreases reproductive capacity of phloem feeding aphids, *Myzus persicae* in potato and wheat and white fly (*Bemisia tabaci)* in cucumber plants. The studies also reported that, the silicon enables the hardening of stem of sugarcanewhich enables the resistance against shoot borer attack (Rao, 1967).

Conclusion

The current review stated the importance of Silica as growth promoter and insecticidal/pesticidal agent on crops. The different studies performed as mentioned in the review illustrates the significant immune-modulating activities of Silica on the growth of crops. The biogenic silica obtained from natural resources has its own potential of growth promotion and insects/ pest's resistance. This review article thus can be utilized as a basis for further studies on silica and its application in agriculture.

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