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SILICON IN THE ENVIRONMENT AND THEIR ROLE IN THE MANAGEMENT OF ABIOTIC AND BIOTIC STRESSES TOWARDS CROP PRODUCTION

Adnan Riaz*1, Shahzad Ali*2, Ihtesham Arshad*3, Sidra*4, Taiba*5, Hassan Nawaz Khan*6, Matie Ullah*7, Kashif Ashraf*8

*1,8Department Of Agronomy, College Of Agriculture, University Of Sargodha, Sargodha 40100, Pakistan.

*2,4Department Of Soil And Environmental Sciences, College Of Agriculture, University Of Sargodha, Sargodha 40100, Pakistan.

*3Department Of Biotechnology, University Of Okara, Okara 56300, Pakistan.

*5Department Of Botany, Government College Women University, Faisalabad 38000, Pakistan.

*6,7Department Of Horticulture, College Of Agriculture, University Of Sargodha, Sargodha 40100, Pakistan.

Correspondence author Email address: adnanriaz6061209@gmail.com or alishahzad8605683@gmail.com

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ABSTRACT

Silicon is a second most abundant element in the earth crust after oxygen but has not been proven to be as essential element for plant growth. Silicon present in earth crust in the form of silicon dioxide (SiO_2) but in this form cannot be taken up by the plants; it's taken up by plants in silicic acid or mono silicic acid {$Si(OH)_4$ or H_4SiO_4}. Many beneficial affects reported in the different crops after their applications and applied silicon fertilizer increases the productivity and sustainability of crop production system. Generally, plants uptake silicon by roots transported to shoots in solution form, after loss of water from stomata, its forms polymerized silica gel that's accumulate beneath the stem and leaf surface. Polymerized gel has been proven to be lake of any role in the morphological functions of plant system. Actually, silicon protects the plant from stresses by two-way mechanism I) accumulation of silicon beneath surface of stem and leaves that's protect the plant physically while II) silicon mediate the natural defense system of the plant at genomic level to produce resistance. In this review, silicon in the environment (soil, water and plants), their role in mitigation of a-biotic (drought, salinity, heavy metals and nutritional imbalance) and biotic stresses (diseases and insect pests) are discussed. There is a complex relationship among the silicon and plant genotypes, species and varied environment.

Keywords: Silicon, Morphological Functions, Sustainability, Genotypes, Polymerized.

I. INTRODUCTION

Silicon have a great importance because only eight abundant elements are present in the whole universe its number is second in the earth crust after oxygen. Silicon contains about 28.2% of the earth crust. Soil mass is made of about 50-70% by silicon dioxide (Ma and Yamaji, 2006). In periodic table it is present in group 14 having atomic weight is 28.0855 it is very important for living organisms on earth. For human being and animal it is considered as essential element but for higher plant it is not essential (Liang et al., 2015). Growth and development of plants is altered by environmental stresses both a biotic and biotic factors causes yield losses globally. Under stressful condition plant adopt several mechanisms for their better survival. To maintain stress tolerance and for healthy growth of plant nutrition is very important. Under various stresses micronutrients provide tolerance (Vanderschuren et al., 2013; Bradacova et al., 2016). Silicon lower the injurious effect of biotic (diseases, insect pest attack) and a biotic (temperature, high salt concentration, drought and nutritional imbalance) stresses (Zhu and Gong, 2014; Wang et al., 2015; Coskun et al., 2016).

Silicon in environment (Soil and Plant system)

Some rocks like orthoquartize and basalt contain silicon in very high concentration ranges from 23-47% and also present in earth crust (Tubana et al., 2016).

Soil: It is present in solid, liquid and adsorbed form silica. Primary and secondary silicates present as solid phase of silicon which is present in crystalline form. Salicylic acid is present in some aquifers with an average rang of 30.38 ppm (Pradeep et al., 2016). In Japan about 380 rivers investigated highest concentration of SiO_2 was 61.5 ppm and lowest was 4.1 ppm (Kobayashi, 1960). Silica is present in air dust storm contain it. Crystalline and amorphous silica known as quartz causes respiratory diseases (Kanatani et al., 2010). Silica is a component of nanoparticles which is measured in field measurement with the help of Nano Aerosol Mass Spectrometer (NAMS) which give 20 (micron) diameters of nanoparticles (Bzdek et al., 2014).

Plant: Plant play role in silicon cycle by taking silicon directly from soil and water which can return back by used and burned, by human and animal feces, leaf fall, by manure or indirectly incorporated in field. Silicon concentration ranges from 0.1 to 10 % on dry weight basis (Currie and Perry, 2007). Plant takes fair amount of silicon from irrigation water and absorbed by plants from soil solution. There are three proteins which act as a transporter of silicon (Lsi1, Lsi2 and Lsi6). Low silicon1 (Lsi1) transport silicon from soil solution to root cells (Ma et al., 2006). Low silicon 2 (Lsi2) transport silicon to apoplast from root cells (Ma et al., 2007). Low silicon 6 (Lsi6) transport silicon to panicles from vascular bundles (Babu Rao and Sushmita, 2017). Monocots like rice, sugarcane, barley and wheat are mainly silicon accumulating and mostly dicots are nanoaccumulator but some dicots like soybean and sugar beet are silicon accumulator (Hodson et al., 2005).

Management of Abiotic and Biotic stresses by Silicon towards Crop Production

Role of silicon in the management of Abiotic stresses

Some physiological processes like ion uptake, respiration, photosynthesis, stomatal behavior, seed germination, and mineral uptake are affected by a-biotic stresses like drought, soil salinity, nutritional imbalance and heavy metals (Singh et al., 2015).

Drought: Due to transpiration water losses occur and closure of stomata take place and photosynthetic activity is reduced. Transpiration mainly occurs through stomata. Silicon deposited beneath the cuticle and form Si-cuticle double layer in this way rate of transpiration is reduced. Application of Si provides tolerance to plant by various mechanisms under water stress condition. Silicon application regulates plasma membrane intrinsic protein (Aquaporin gene) and inhibits ROS^- induced aquaporin activity in plants. Root hydraulic conductance is increase by silicon application. Higher root hydraulic increase water uptake and transportation which maintain the photosynthetic activity and resistance to drought condition (Luyckx et al., 2017).

Table 1: Tolerance mechanism of different crops against drought stress with references

Stress	Crop	Mechanisms	References
Drought	Sorghum	Transpiration rate and physiological process increase.	Yin et al., 2014
Drought	Bluegrass	Morpho-physiological process increases and also plant water relation.	Saud et al., 2014

Salinity: High salt concentration in the environment plant is stressed by ionic, osmotic and oxidative stressors. Salinity affects ground water, soil and agricultural productions. Uptake of sodium and chlorine is reduced by silicon. In rice toxicity of NaCl is reduced by precipitation of silicon as SiO_2 which block transpiration bypass flow (Yeo et al., 1999). With silicon treatment hydrogen peroxide, lipid per oxidation and electrolyte leakage is reduced (Abdelaal et al., 2020). Method used for cultivation (soil and hydroponic), application method (root and foliar), form (silica ions and silica nanoparticles), concentration, duration and intensity all these influence silicon effect on salt tolerance (Zhu et al., 2019).

Table 2: Tolerance mechanism of different crops against salinity stress with references

Stress	Crop	Mechanism	References
Salinity	Okra	In root and shoot Na and Cl reduced.	Abbas et al., 2015
Salinity	Canola	Toxic ion and hydrogen peroxide reduced.	Farshidi et al., 2012

Heavy metals: In contamination of soil heavy metals and trace elements are raising problem which cause serious problem of food contamination and environmental issues (Imtiaz et al., 2016). Toxicity of various metals is reduced by silica application. Silicon reduced various metals toxicity like Al, Zn, As, Fe, and Mn and availability of phosphorus is increase (Guntzer et al., 2012).

In rice oxidizing capacity of roots is increased by silicon which converts ferrous into ferric iron and reducing its toxicity and increase availability for plants (Ma and Takahashi, 2002). Aluminum and manganese in excess also have severe effect on plants like wheat, rice, cucumber, soybean etc. Silicon and aluminum form inert alumino-silicates and sub colloidal or by blocking apoplastic pathway which reduces phytotoxic aluminum in soil.

Table 3: Tolerance mechanism of different crops against heavy metals stress with references

Stress	Crop	Mechanism	References
Cu	Wheat	Cu translocation to shoot is reduced.	Keller et al., 2015
Pb	Cotton	Antioxidant enzymes activities are increased.	Bharwana et al., 2013

Nutrients imbalance: Nutritional imbalance causes different problem in agricultural production because proper plants functioning is disturbed like no formation of chlorophyll content and no food formation. In barley and rice beneficial effect of silicon is observed in phosphorus deficient condition. Phosphorus accessibility is controlled by Mn and Fe, so silicon increases the phosphorus accessibility by reducing Mn and Fe in plants (Ma, 2004). Diseases caused by high nitrogen availability mutual shading and sensitivity of plant are reduced by increasing the availability of silicon. Maize plants having magnesium deficient treated with silicon increases their growth and chlorophyll content and sugar content level by hormonal and metabolic changes (Hosseini et al., 2019).

Role of silicon in the management of Biotic Stresses

Many biotic stresses are responsible for yield reduction and crop production. Worldwide more than 50% losses occur due to a biotic stress (Wang et al., 2003). Silicon application provides resistance to plant against biotic stress.

Mechanisms involved controlling diseases and insect pests

There are two mechanisms of silicon to control diseases and pathogens. One is as physical barrier silicon deposited on tissue surface or beneath leaf cuticle which inhibit insect pest and fungal penetration (Samuels et al., 1991). Second mechanisms are providing signals to natural defense system to produce defense compounds like phenolic compounds, lignin and phytoalexins (Ma and Yamaji, 2006).

Diseases: Silicon enhances resistance against various diseases. Magnaporthe grisea cause rice blast which is fungal disease pathogen because leaf blast during vegetative growth and neck blast during reproductive stage of growth (Ma, 2004). Silicon application suppresses leaf and neck blast at various growth stages.

Powdery mildew caused by (Sphaerotheca fuliginea) in strawberry, wheat and cucumber. When silicon content is increases in plants attack of powdery mildew is minimized. Other diseases bacterial blight, stem rot, brown spot in rice and corynespora, and fusarium wilt of cucumber is minimized by increasing silicon supply (Datnoff et al., 2002). Defense related enzyme activities such as β-1, 3-glucanase, phenylalanine ammonia lyase (PAL), chitinase and superoxide dismutase are responsible for disease resistance (Waewthongrak et al., 2015).

Table 4: Tolerance mechanism of different crops against diseases stress with references

Disease	Crop	Mechanism	Reference
Leaf Blast	Rice	Activities of β-1, 3-glucanase and chitinase increase.	Souza et al., 2015
Powdery mildew	Black gram	Defense related proteins expression increased.	Parthasarathy and Jaiganesh, 2016
Anthracnos e	Tomato	Thickness of cuticle increased.	Somapala et al., 2016

Insect pest: Higher silicon content in growth medium and soil having significant role in resistance to insect pest infection. Cuticle is hardened due to silicon which resists insects. Silicon fertilizer applies to soil increase uptake by 32% in rice and reduced the boring capacity of Diatraea saccharalis (Sidhu et al., 2013).

Accumulation of silicon in internodes epidermal tissues of sugarcane increased resistance to Eldana saccharina by reducing stalk penetration (Keeping et al., 2009). Foliar application of calcium silicate to crops like wheat, rice, cucumber, cotton and sugarcane increased white fly nymph mortality which causes significantly yield losses in these crops (Correa et al., 2005).

Table 5: Tolerance mechanism of different crops against insect-pest stress with references

Insect-pest	Crop	Mechanism	Reference
Stalk Borer	Sugarcane	Stalk length and stalk percent reduced.	Keeping et al., 2013
Fall armyworm	Rice	Larval survival and feeding preference affects.	Nascimento et al., 2014

II. CONCLUSION

From the reviewed literature, it could be concluded that silicon is a beneficial element widely founded in the earth crust after oxygen. Silicon protects plants from the different types of biotic and abiotic stresses and produce sustainability in crop production system. In case of regular availability or application, silicon increases the growth and productivity of plants. According to many researchers, their beneficial effects on plants are observed but their variation among the silicon and plant genotypes, species, and environment demands more detailed studies to understand the interaction between silicon and plant response under stress condition.

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IV. CONFLICT OF INTEREST

The authors declare no conflict of interest.

V. DATA AVAILABILITY STATEMENT

The data present in this review that support the findings of this study are openly available.

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