The Pharma Innovation Journal 2022; 11(4): 1647-1654

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(4): 1647-1657

www.thepharmajournal.com
Received: 01-01-2022
Accepted: 09-02-2022

Mechanisms of silicon for abiotic stress tolerance in higher plants: A review

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Abstract

Silicon has been considered as a beneficial detoxification agent, since due to anthropogenic activities in the environment, there have been increased contaminants. It also has an impact on the sustainability of agricultural production. In this regard, Si plays a major role in amelioration of stresses imposed by both biotic and abiotic factors, for example extreme amount of heavy metal in plants. There are different systems of silicon intercession in plants, which incorporate decrease of heavy metal take-up, change in pH of soil, silicon substantial metal development that works by chemical and physical pathways. Silicon is known to be useful in moderating aluminium, manganese, cadmium and substantial metal toxicity and furthermore, saltiness or salinity, drought, freezing and chilling stress. The important function of Si in decreasing the abiotic stress includes: Chelation and stimulation of antioxidant system in plants, restriction in movement of toxic metal ions in growth media, root to shoot translocation, co-precipitation of complex formation of heavy toxic metal ions with silicon, uptake processes, changes in structure of plant. In any case, these components are related with plant species, genotype of the plant, metal components, conditions for development and the time of stress imposed to plants. Exogenous silicon use has been archived to build substantial metal resistance in plants.

Keywords: Metal, plants, silicon, stress, toxicity

Introduction

Rapid and unplanned urbanization and industrialization, as well as labor-intensive farming, have put enormous strain on the worldwide environment. The contemporary era's population boom has resulted in mining, smelting, plastic production, e-waste manufacturing, and an abundance of fertilizers, herbicides, and waste water irrigation have all contributed to hazardous pollutants release into the atmosphere, particularly in farming soils. (Bi *et al*., 2018; Ma *et al*., 2019) [10, 66].

Si, after oxygen, is the most frequently occurring element on Earth as well as in soil and plants benefit from it in terms of growth and development under a variety of environmental situations. (Liang *et al*., 2007; Rasoolizadeh *et al*., 2018) [52, 79]. Since silicon is a plant nutrient and an essential element, it plays a major role in plant growth, yield, and chlorophyll. Plants use silicon as a nutrient acquired through their roots, to alleviate the impacts of abiotic stresses which include metal toxicity, salinity, water stress, temperature stress and nutrient imbalance. There are basically two mechanisms through which Si eases the toxicity of metals, these are internal and external. For external, silicon changes the metal formation to reduce metal concentration by adding a silicon compound, reducing activity and absorption of metal. Then again in internal system silicon lessens the unfriendly effects of metal toxicity by stimulating the enzyme activity. Anyway the defensive function of silicon can be accredited to a collection of polysialic acid in the cells of plant. Accordingly, with intensification in polysialic acid, the resilience in plants is improved and this by implication hinders with the stress factors. Cadmium is accumulated in higher amount in the root portion than stem. Hence Si is also is seen in root of the plants, making a physical barrier, and reducing the uptake of heavy metals. Various environmental and soil conditions, however, have a considerable impact on the bioavailability of Si in the soil and its delivery to plants. High rainfall causes Si leaching and a low pH in the soil, both of which have detrimental effects on biological Si pools in the soil and make Si less bioavailable to plants (Schaller *et al*., 2021) [85].

Metal: From being important to toxic

Metals can be classified as elements which are not essential, such as Cadmium, Mercury, Palladium, Chromium, Arsenic, and Silver which are potentially toxic to plants and are the

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most dangerous contaminants to plants (Feng *et al*., 2021) [31]. The essential micronutrients such as Copper, Zinc, Iron, Manganese, Molybdenum, Nickel, Cobalt, which are needed for healthy plant growth and development. The metals which are essential to the crop take part in different processes. Generally, any crop will grow normally when given nutrient quantity matches the requirement that plant needs. The nutrient deficiency will result in symptoms which may even lead to mortality under extreme conditions. Hence if there is more amount of metal, it may reduce and inhibit the plant growth, which is caused by structural, biochemical and physiological changes. If up taken in large amount, the metals will change uptake, translocation, also accumulation of element in any crop. Heavy metals in the soil have a negative impact on crop development, photosynthesis, biomass, and productivity, as well as limiting the intake and transfer of important nutrients to plants (Adrees *et al*., 2015; Awan *et al*., 2020) [1, 5]. Dangerous impacts which metal imposes results in restrained growing life, reduced energy, water balance and at last it leads to senescence.

Heavy metal toxicity in crop plants

Because of unfavourable ecological effects, heavy metal in soil has come out as an important concern. Furthermore, leafy vegetables absorb and collect more heavy metals in their leaves than non-leafy vegetables, putting them at a higher risk of poisoning, devastation. These vegetables have the potential to be the ultimate source of heavy metals to make their way into the food chain (Fatemi *et al*., 2020) [30]. The land for producing crops has metal in great amount such as Cadmium, Lead and Zinc. This land will show some bad impact on plant, soil biological activity, human, animal health, also biodiversity. There have been different approaches including phytoextracts, mobilizers and more sustainably, use of silicon has contributed in mitigating heavy metal toxicity in plants. Although Si is not included among the necessary elements, it is involved in plant growth and development and has a broad spectrum of functions in plant metabolism, particularly in graminaceous and cyperaceous species (Liang *et al*., 2005) [51]. Furthermore, poor soil management and a high rate of crop harvesting had a negative impact on the Si concentration in the soil solution and, as a result, plants that were stressed in many ways (Puppe, 2020; Schaller *et al*., 2021) [77, 85].

Silicon: A multibranched element to reduce toxic metals in crops: The improvement of crops to tolerate toxic metals derived from silicon is quite precise. Silicon has a beneficial role in detoxification and attributed to different processes of crop. Soil amendments containing Si or Si fertilisers may change the structure of the bacterial population, the physiochemical properties of the soil, and the limitation, immobilisation, and transformation of contaminants like cadmium (Ma *et al*., 2021; Zeng *et al*., 2011) [66, 102].

The outside process of promoting metal toleration is because of pH enhancement when we apply silicate which results in metal silicate precipitation that eventually decreases obtainability of metal. In crops, silicon influences movement of metals in different areas of crop and permits to live through the toxicity of metal. Crops shift the capacity of gathering silicon, more aggregators; for example, monocot normally acquires more noteworthy advantages, despite the fact that toxicity of metal might be reduced with silicon. In case of rice, silicon modifications indicated decrease in aggregation of metal, and also enhanced the metals (Cadmium, Copper, Lead, Zinc), polluted the soil which was acidic. Si is likewise described as to expand plant energy. Previously, in the presence of Si, numerous plant species demonstrated a significant improvement in their growth under heavy metal stress like wheat, rice, cotton, maize and peanut (Liang *et al*., 2007) [52].

Accumulation of Zn was fundamentally repressed by silicon in various areas of the crop, for example, in cotton and maize, the underground part and also the leaf. It has been reported that silicon limits Cadmium metal toxicity by diminishing particle retention and movement in seedlings of rice from underground to the above ground part. Use of Si likewise lessened fat or triglyceride per oxidation and boost the living matter of crop under substantial noxious metal. Si is helpful to reduce Aluminium content in Barley. Correspondingly, diminished Aluminium amount by using Si is reported in the underground root part, leaf and stem part of seedlings of rice as well as peanut. Rice seedlings absorb Si from the soil as silicic acid, which is linked to a reduction in heavy metal transport into the rice seedlings (Cui *et al*., 2017) [16].

Si alteration when used as detoxifying element in aluminium harmfulness is accounted in great millet, corn, *Solanum lycopersicum and Gycine max*. Significant decrease in silicon in farm soils is seen when we remove the debris which has Si while yield collection. Therefore, if applied externally, it will turn into a pattern sooner to repay it's exhaustion in soils, all the while receiving its reward of improving plant development and mitigating the metal toxicity.

Silicon uptake mechanism

The concentrations of Silicon differ in great amount in part of crop above ground, and range between 0.1- 10% (Epstein, 1994, 1999; Ma and Yamaji, 2008) [26-27, 63]. This concentration of silicon in plant is because of Si uptake differences. The plants of gramineae family show more silicon uptake as compared to other species, on the other hand, most plants that belong to dicotyledonous category show passive absorption of silicon (Ma *et al*., 2001) whereas legumes avoid silicon take-up. On the other hand, strawberry and cucumber take up Silicon passively (Takahashi *et al*., 1990; Ma *et al*., 2001; Mitani and Ma, 2005) [93, 68]. Other than rice, wheat (Van der Vorm, 1980; Jarvis, 1987; Casey *et al*., 2003) [98, 43, 11], barley and ryegrass also take silicon actively.

Defense mechanisms of silicon

Si is routinely consumed by plants by arrangement of monosilicic acid. The concentration of Si as silicic acid in soil fluctuates between 0.1 and 0.6 mM, which is roughly two times higher than the concentration of phosphorus in the soil solution (Epstein, 1999) [27]. Because Si in the soil solution is monomeric or monosilicic (H4SiO4), it is easily absorbed by the root system and translocated to areal portions of plants, where it accumulates (Hodson *et al*., 2005) [39].

Silicon's defence mechanism show up all through the plant. Si, in leaf, is utilized in making various structures for example, epidermis and hair. It is likewise gathered in the form of phytoliths and spines. In crops, there are unique pathways or components through which Si removes reactive oxygen species and also ameliorates metals which are toxic. In case of cell culture, the absorption of metal and its movement from the underground root to the above crop part is diminished by Si. Si, through various methods also reduces toxic metal, for example, gene expression regulation which is involved in transport of metal and metal-chelation, partaking in metal co-precipitation, variation in structure of plant, invigorating the enzyme activity. By mixing cadmium-silicon, the tolerance of Cd increases in birch plant (Song *et al*., 2009) [92]. This exhibited the function of silicon in decreasing toxic metal take-up and restricting root to shoot movement, and furthermore invigorating the activity of enzyme. Si can change the qualities of soil by improving air and water regimes, boosting nutritional content (nitrogen, phosphorus, and potassium), decreasing heavy metal toxicity through improving soil physical and chemical properties, and forming new silicate complexes (Adrees *et al*., 2015, Zhu *et al*., 2019) [1, 104]. It has been reported by numerous analysts that the co deposit of silicon with metal can lessen the concentration of these toxic particles in plants. It has been accounted for that, utilizing a few systems, for example, root emitting fluids; rise in pH level, Si restricts aluminium absorption in plant roots, it hastens aluminium concentrations on the surface of root. In an overall characterization, components of Si detoxification are assembled as physical or chemical processes. The latter are involved in co precipitation of Si with metal, whereas physical processes, by altering the structure of plant, reduce the transfer of metal to above ground parts, for example, apoplastic barrier. The root system of plants absorbs Si from the soil and improves the plant's living status by lowering heavy metal uptake and translocation from root to shoot, activating the antioxidant system, chelate compartmenting, and controlling heavy metal transporter expression of genes (Adrees *et al*., 2015; Etesami and Jeong, 2018) [1, 28]. In general, silicon takes part in process of reducing the stress in plants that are subject of abiotic stress as well as metal toxicity in a few significant systems, along with stimulating the antioxidant enzyme activity so that the reactive oxygen species removal is enhanced, complex formation, restricting harmful particles of metal in plant, precipitation and aggregation to acquire stability and toughness in leaves of plant tissue, mobility of water, and providing nutrient to the plant and co precipitating the metal toxicity. Si also reduces heavy metal toxicity, activates soil phosphorus (P), and improves P availability and absorption, which is then taken up by plant roots together with other necessary nutrients (Tripathi *et al*., 2015) [96].

Metal immobilization in soil by silicon

Metal immobilization is a lot more straightforward process to clarify the silicon determined advantages. This mechanism has been accounted for in a few studies (Sahebi *et al.,* 2015) [82]. The factors such as pH of soil and organic matter control the availability of metal and because of the increase in pH of soil by formation of silicate complex, the availability of metal decreased (Chen *et al*., 2000; Morikawa and Saigusa, 2002; Liang *et al.,* 2005; Treder and Cieslinski, 2005; Gu *et al*., 2011) [10, 70, 51, 94]. In rice, use of silicon rich modifications was known in expanding soil pH. Likewise, in banana, for the soils contaminated with lead, application of silicon was found to be helpful in reducing lead uptake. The diminished bio-accessibility of lead was discovered to be related with fundamentally increased pH of soil and less extent of exchangeable lead present in the soil (Li *et al*., 2012). Moreover, silicon forms silicate complexes in soil and changes the toxic metal speciation to non toxic (Ma *et al*., 1997; Liang *et al*., 2007; Putwattana *et al*., 2010) [52, 78]. In soils amended with silicon, generally cadmium was present in oxide form or was absorbed by oxides of Iron-Manganese (Liang *et al.,* 2005) [51]. It is seen that availability of Al to plants can be restricted by aluminium-silicon complex formation, such as hydroxyaluminosilicate (Hodson *et al.*, 1997) [13]. It was demonstrated that by fastening the organic matter bound to chromium fraction precipitation will reduce the exchangeable chromium in the soil contaminated with chromium by application of silicon (Zhang *et al*., 2013) [55]. Also, the diminished metal mobility in soil contaminated with lead by the application of silicon (Shim *et al.,* 2014) [88]. Examination with X-beam diffraction investigation has shown the development of insoluble lead-silicate in soil. Likewise, in soil contaminated with cadmium and zinc, it has been seen that silicon application has fastened the development of comparatively stable portions of zinc and cadmium (Cunha *et al.,* 2008) [76].

Antioxidant defense mechanism stimulation

Substantial metal stress instigates excessive reactive oxygen species formation. This leads to crop plant metabolic disorders (Adrees *et al.*, 2015; Ahmad *et al.*, 2019) [1, 2]. In this specific situation, non-enzymatic and enzymatic antioxidant mechanisms which are invigorated by silicon assist with reducing the oxidative stress by lowering the reactive oxygen species formation. Application of silicon also reduces the hydrogen peroxide and electrolyte leakage, under cadmium stress in case of *Solanum nigrum* (Liu *et al.*, 2013) [55]. Silicon application also reduced the oxidative stress compounds for example hydrogen peroxide, malon dialdehyde and electrolyte leakage in plants suffering with zinc (Anwaar *et al.*, 2015) [4], cadmium (Hussain *et al*., 2015) [41] and lead (Bhatti *et al.*, 2013) [9] stress. In maize, rice, peanut and wheat, the impact of supplementing silicon on antioxidants during cadmium stress has been noted (Lukačová *et al*., 2013; Zhang *et al*., 2008; Tripathi *et al*, 2012; Shi *et al*., 2010; Hussain *et al*., 2015) [95, 103, 41, 56]. Under stress of heavy metals, the activities of non-enzymatic and enzymatic antioxidants for example, ascorbic acid, glutathione, etc have been accounted in various species of plants (Song *et al*., 2009; Li *et al*., 2012) [92]. Under manganese, zinc, copper and lead stress, detoxification intervened with silicon by invigorating both non-enzymatic and enzymatic antioxidants have additionally been accounted (Wu *et al*., 2013) [100]. Considering all the past studies, induction of antioxidant mechanism in plants has been observed by silicon application, accordingly enhancing the resistance of plants to stress (Coskun *et al*., 2019) [2].

Compartmentation in plants

Improved compartmentation of metal with supplementation of silicon in tissues of the plant has been seen in a few experiments. It has been observed that in barley, the impact of silicon in easing manganese toxicity was not the consequence of decrease in concentration of manganese; however the reason was enhanced compartmentation inside the tissues of leaves (Williams *et al*., 1957) [99]. Another compartmentation level with supplementation of silicon, which is generally controlled by the process of translocation and results in increment in concentration of metal in roots of the plant rather than shoots, has been observed (Yamaji N *et al*., 2008; Keller *et al*., 2015) [63, 45] It was reported that when treated with silicon, the zinc transport to shoot from plant root decreased, and an increment in zinc getting attached to the cell wall lead to reduction in concentration of zinc in rice shoot (Yamaji *et al*., 2008) [63]. In case of wheat, cadmium translocation to the shoot from root was reduced by application of silicon (Naeem *et al*., 2015) [71]. Shi *et al*., 2005 noted that cadmium translocation from root to shoot decreased by about 33% by silicon application. This plainly demonstrated that cadmium accumulated in epidermis and endodermis, in any case, a high measure of silicon was deposited more close to endodermis as compared to epidermis. Due to this deposition of silicon in endodermis, the cadmium translocation reduced from epidermis to endodermis. In expansion, when silicon was applied to rice, cadmium deposition decreased in the shoots, this was related to increase in cadmium compartmentalization in cell wall of the roots (Zhang *et al*., 2008) [103]. In cucumber, under stress of Mn, silicon was additionally seen to build the localization of manganese in cell wall (Maksimović *et al*., 2012) [24]. Besides, in the plants treated with silicon, symplast had less manganese translocation (less than 10%), and cell wall had more than 90% manganese (Rogalla *et al*., 2002) [81]. Subsequently, detoxification of the toxic metals interceded by silicon by their compartmentation into various tissues of the plant is a major component of the valuable role of silicon.

Chelation mediated reduction of metal toxicity with silicon application

The detoxification of heavy metals by silicon mediation transcendently incorporates metal chelation by organic acids or flavonoid-phenolics. In maize, 15 times expanded phenol exudation has been seen when supplemented with silicon (Kidd *et al*., 2001) [47]. In maize, under aluminium stress, an impressive increment of malic acid upon application of silicon has been revealed (Barceló *et al*., 1993) [23]. Chelation of aluminium with malic acid has resulted in reduction in toxicity of aluminium. In Bamboo plant, Silicon plays a role in enhancing the Cu(I)S ligand concentration that helps in chelating Copper and enhancing it's segregation to a form which is less harmful (Collin *et al*., 2014) [14]. In wheat, reduced copper translocation from root to shoot when supplemented with silicon was observed. This may be due to an increment in the citrate or malate proportion in roots of wheat. These examinations, altogether, propose that silicon reduces the phytotoxicity in plants by enhancing the heavy metal chelation (Keller *et al*., 2015) [45].

In Arctic soils, Si availability was found to be substantially linked with phosphorus mobilisation (Schaller *et al*., 2019) [84]. Some reports also show that silicon helps in expanding the mobilization of phosphorus and also in enhancing the soil respiration in soils that are lacking phosphorus. Other than a significant nutrient element, phosphorus is also helpful in soil biochemical activities. An impressively high number of reports have demonstrated the significance of phosphorus to lessen the heavy metal bioavailability through immobilization of metal ions in soil (Gupta *et al*., 2014) [36]. Subsequently, silicon intervened mobilization of phosphorus appears to be an important alternative for managing availability of phosphorus sustainably, just as for limiting the losses caused by heavy metals in agro-biological system.

Metal stress tolerance by structural alterations in plants

Supplementation of silicon helps in conquering the toxicity due to heavy metals by improving the morphology and anatomy of the crop plants. Prominent models where the plant height, length of root, leaf number and size has been increased by application of silicon under zinc, lead and cadmium stress in the plant (Farooq *et al*., 2013; Bharwana *et al*., 2013) [3, 7]. In barley, it has been observed that treatment with silicon and chromium tends to increase the length of root, height of plant, tiller number, and the size of leaves in comparison with the plants that were treated with only chromium (Ali *et al*., 2013) [3]. Likewise, the length of root and the size of shoot also essentially increased when treated with silicon as compared to no treatment with silicon (Farooq *et al*., 2013) [3]. In maize, silicon was also reported to enhance the thickness in epidermal layer of leaf when exposed to manganese stress (Doncheva *et al*., 2009) [23]. An enhancement in the diameter of xylem, mesophyll, epidermis as well as collenchyma when treated with silicon was reported under zinc and cadmium stress (Cunha *et al*., 2009) [17]. Development of apoplastic boundaries in endodermis near to apex of root when silicon was present in plants treated with cadmium in wheat (Greger *et al*.,2011) [33]. Accordingly, basic modifications incited by silicon under toxic metal stress may clarify the mitigation of toxicity by metals.

Metal coprecipitation by silicon application

Numerous studies recommend that silicon can mitigate the metal toxicity in plants by co-precipitating the metals. For instance, when plants were under aluminium stress, it was suggested to treat them with silicon, since it would lead to formation of aluminosilicates in the apoplast of plant root, which eventually results in detoxification of aluminium (Barcelo *et al*., 1993; Cocker *et al*., 1998) [6, 13]. Silicon was also accounted for zinc co precipitation as their silicates in epidermis of leaf cell wall (Neumann *et al*. 1997) [72]. Si-heavy metals are metals that have a lot of silicon in them. Co-precipitation aids in cell wall thickness by creating strong silica barriers that bind and prevent heavy metal transport (Bhat *et al*., 2019) [8].

The absence of Si–Cd compounds in maize plants treated with Si under Cd stress is also supported by the findings (Dresler *et al*., 2015) [25]. In rice, co precipitation of silicon with cadmium was reported to decrease the concentration of heavy metals in leaves (Gu *et al*., 2011). It was reported by Zhang *et al*., 2008 [103], that silicon and cadmium accumulated in the centre and around the phytoliths of rice shoots.

Gene expression regulation

Mechanism of detoxification of heavy metal in plants is represented by synthesis of phytochelation (Rea *et al*., 2012) [79]. The mitigation of toxic metals by silicon mediation is ascribed to the altering gene expression role of silicon. In Arabidopsis, supplementation of silicon was seen to stimulate genes to produce a chelating agent which is metallothioneins under cadmium stress (Li *et al*., 2008). In rice supplemented with silicon, down regulated gene expression which encodes heavy metal carriers and also up regulated gene expression liable for transport of silicon has been observed (Kim *et al*., 2014) [48]. Likewise, under copper stress in Arabidopsis species, the reduced metallothionein expression of gene and enhanced phytochelatin synthase 1 has been observed (Khandekar *et al*., 2011) [46]. As of late, in rice, silicon supplementation under cadmium stress was reported to up regulate the OsLsi1 gene expression and down regulate Nramp5 expression, which is known to transport cadmium (Ma *et al*., 2015). Moreover, there are plant species that are poor accumulators of silicon and do not carry silicon transporters such as NIP III aquaporin and are therefore called as poor Silicon accumulators. These species are from the families of brassicaceae, lineaceae, solanaceae (Sonah *et al*., 2017; Shivaraj *et al*., 2017) [89, 91].

Approaches to improve accumulation of silicon in plants

Useful silicon impact to alleviate harmful impact of metals is generally evident that amass in plants at significant levels of silicon (Ma *et al*., 2001; Yamaji *et al*., 2008) [63]. Si aggregation depends on the silicic acid availability in soil and also the characteristic capacity of plant to uptake silicon. If we apply silicon rich fertilizers or modify the soil properties, the availability of silicon in soil will be improved, while the genetic alterations can enhance the inherent limit of any species for accumulation of silicon.

Fertilization by silicon: Consistent cropping of the crops that accumulate silicon results in a noteworthy decrease of available silicon to plants in the soil (Meunier *et al*., 2008) [67]. If rice is cultivated for five long years continuously, then it may deplete maximum amount of silicon available to the plants (Desplanques *et al*., 2006) [21]. Also, some soils have low degree of silicon, especially the plant-accessible forms, and these soils incorporate Oxisols, Histosols and Ultisols and also the soils that are made up of large quartz fraction. Silicon is absorbed as monosilicic acid and its fixation in soil will decide the fraction of plant accumulates (Henriet *et al*., 2006) [37]. The concentration of this acid can be increased by fertilization and this has become a typical practice in areas where intensive cropping system is followed, especially for the soils which are low in the soluble silicon (Guntzer *et al*., 2012; Tubaña *et al*., 2015) [35, 97]. It has been observed that there were less concentrations of zinc and copper in plants grown with silicon based fertilizers (Jarosz *et al*., 2013; Ning *et al*., 2014) [42]. Some studies, on the other hand, have found that the fertilisation method can affect the quantity of Si accessible to the plant (Ouellette *et al*., 2017) [74]

Modification in soil properties: The rich amount of silicon present in soil is not related to plant available silicon concentrations (Tubaña *et al*., 2015) [97]. Silicic acid concentration in soil is impacted by a number of soil factors, for example, temperature, pH, soil weathering, dampness, redox potential of soil, clay amounts, minerals, organic matter and oxides or hydroxides of iron or aluminium (Savant *et al*., 1997) [83]. The amorphous and crystalline silica solubility is around steady from pH 2-8.5, and is rapidly increased when pH is 9. The pH of the soil also alters the silicon complex formation with other elements, for example, the monosilicic acid amount which is consumed by oxides of aluminium or iron shows an increase from a pH of 4-10. Under soil acidic conditions, the amount of free silica increases, this was stated by Kaczorek and Sommer, 2004 [44]. Likewise, with decrease in ph, the silicon availability increases (Höhn *et al*., 2008) [40]. In such manner, the use of fertilizers producing acids increase the silicic acid concentration in soil solution, whereas high organic matter and liming reduce the silicic acid concentration and mobility.

Genetic gain approaches: Two silicon transporter genes were identified by utilizing low silicon mutants of rice, and this has been an achievement that fastened the silicon research by numerous folds (Ma *et al.*, 2015). One gene responsible for silicon uptake from soil to the root cells is a passive transporter which belongs to an NIP group (Mitani *et al*., 2009; Deshmukh *et al*., 2016) [69, 19]. A few homologs of Lsi1 are recognized and practically approved in various species of plant. Lsi2 is another gene which encodes a functioning efflux carrier and has a place in cation transport family. The data about Lsi1 and Lsi2 was useful to comprehend the silicon uptake from root and ensuring the transfer to aerial parts (Pandey *et al*., 2019) [75]. As of late, Deshmukh *et al*., 2015 [20] demonstrated the arrangement of plant species as high or poor silicon accumulator in view of the presence of Lsi1 homolog. The variation in interspecies can be adequately clarifies by the Lsi1 homolog presence. This can be explained by Lsi1 homolog characterization. This interspecies variation, running from 0.1-10% has been accounted for concentration of silicon, despite the fact that these variations have all the earmarks of being restricted at intraspecific levels (Hodson *et al*., 2005) [39]. For instance, the silicon concentration in sugarcane has been seen to run from 6.4-10.2 mg^{-1} in shoots of various genotypes (Deren *et al*., 2001) [18]. Likewise, in a study of around 400 barley cultivars, the concentration of silicon in barley grain extended from 1.24-3.80 mg^{-1} (Ma *et al*., 2003). Japonica rice cultivars generally accumulate greater silicon than the indica cultivars (Ma *et al*., 2007).

Conclusion

Natural and artificial activities have brought about a higher convergence of toxic metals in farmlands which lead to serious unfavourable consequences for crop production and profitability and also for human health. In this manner, silicon has risen as handy choice to diminish phytotoxicity of heavy metals in plants. Gainful impacts of silicon are accounted by a few studies and also clarified by various potential processes. Numerous studies contend that utilization of silicon fertilizers comprise an essential way for mitigating the metal stress. Simultaneously, the upgrade of genetic potential to take up silicon would speak to a road to upgrade their response to silicon in plants. This technique would fit well in a sustainable agriculture program to enhance tolerance to heavy metals in plants.

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