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A REVIEW :

Interection of silicon on heavy metal and other stresses in crop plants

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SUMMARY : Silicon is the most aboundant element in soil and is beneficial for a large variety of plants. It is concentrated in plant tissues in quantities similar to that of macronutrients. Considerable damages to plants caused by abiotic stresses such as drought stress, salinity stress, heavy metal stress and nutrient imbalance, as well as biotic stresses like insect pests and pathogens and even herbivorous attacks, have been reported to be reduced significantly by silicon application. Soil contamination with toxic heavy metals (such as Cd ,Pb, As, Hg, Zn) is becoming a most devasting problem worldwide because of the rapid development of social economy. Silicon significantly improved the growth and biomass of crop plants and reduced the toxic effects of heavy metals after different stress periods. Si treatment ameliorated root function and structure compared with non-treated crop plants,which suffered severe root damage. Silicon plays a substantial role in alleviating heavy metal toxicity in crop plants. Also, silicon may reduce the toxic effects of heavy metals in soil. It may protect the foliage and increase light uptake and reduce respiration. Therefore, in this review, we discussed the effects of silicon on heavy metal stress in especially field crops.

KEY WORDS :
Silicon, Heavy metal, Field crops, Soil

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BACKGROUND AND OBJECTIVES

Silicon constitutes a major substantial percentage of different soil types, generally about 31% (Sposito, 1989). In soil solutions, silicon is found mostly as uncharged monomeric silicic acid at concentrations from about 0.1 mM to 0.6 mM Epstein (1994) or upto about 0.8 mM at equilibrium Lindsay (1979) when the solution pH is below 9 Ma and Takahashi(2002).Silicon (Si) is an abundant element in the Earth'scrustand plays a role in heavy metal all eviation in plants by different mechanisms Greger *et al*., (2016). Sireduces the translocation of Cd from roots to shoots and thus, prevents the adverse effect of Cd on photosynthetic machinery and grains Greger and Landberg (2008). How ever, Cd in high concentration is also trapped in roots through vacuolars equestrations, leading to decreased Cd translocation in aerial parts of the plants Liu *et. al* (2013). Phytochelatins (PCs) and metallothioneins (MTs) may bind to Cd before transporting the complexes into the vacuoleor out of the cell by ATP-binding cassette transporters in few plants Jasinski *et al.* (2003). PCs are formed from glutathione by the induction of *PCS1* gene Semane *et al.* (2007). Further, MTs are involved in detoxifying cytosolic environment of the cell from Cdtoxicity Dal Corso *et al.* (2010). The heavy metal is taken up in to the cell via carriers,such as low-affinity cation transporters and Fe-regulated transporters in plants Takahashi *et al.* (2011). Among the Fe transporters, *IRTs* and NRAMPs have been reported to take up heavy metals. *IRT1* is essential for root Fe up take in response to Fedeficiency but it also accepts Cd as a substrateand is involved in the root-to- shoot transport of Cd Rogers *et al.* (2000). In a transgenic study, elimination of *NRAMP5* transporter reduces Cd uptake in rice Ishikawa *et al.* (2012). Additionally, the ferricchelate reductase (*FRO*) gene may perform key functions in Feacquisition in plants. It was reported the inhibition of Fe translocation when bean plants were exposed to chromium (Cr) in nutrient solutions Barcelo *et al.* (1993). Also, Craffects Fe uptake indicots either by inhibiting the reduction of Fe(III) to Fe(II) or by competing with Fe(II) atthesite of absorption. Inaddition, *IRT1* is induced in response to Fe-deficiency and is capable of transporting minerals and heavy metals Vert *et al.* (2002). Further, organic acids such as citrate and malate are major chelators in both Strategy I and II plants, which bind Feat the site of uptake and facilitate long-distance transport in plants Kabir *et al.* (2012). To complete a life cycle, plants are continuously exposed to various abiotic stresses and sometime multiple stresses.These stresses in turn causing the generation of various reactive oxygen species (ROS), such as singlet oxygen (1O2), superoxide(O-2), hydrogen peroxide (H_2O_2), or hydroxyl radicals (OH) in cells .These ROS can cause serious oxidative damage to the protein,DNA, and lipids of cell components Tripathi *et al.* (2017). Therefore, ROS scavenging is most important defense mechanism to cope with stress condition in plants Das and Roychoudhury (2014). According to previous reports, exogenously Si can improve the ability of ROS scavenging by regulation of antioxidants enzyme activity. Further more, regulation pattern across various crop plants is different depending upon the exposure time of the stress Kim *et al.* (2016). Therefore, here, we discussed various possibilities based on previous literature survey and our understanding the role of Si in modulating antioxidant activities in plants during abiotic stress.

Defense mechanism against rosgeneration :

Plants continuously produce several ROS during metabolic process like photosynthesis and respiration processes in cell organelles such as mitochondria, chloroplast, and peroxisomes. In plants,superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX) are the main enzymatic antioxidants, whereas carotenoids, tocopherols, ascorbate, and glutathione are classified as the non-enzymatic antioxidants. SOD are distributed in a different form in various plant organs such as chloroplasts (Cu/ZnSOD, FeSOD), cytosol (Cu/ZnSOD) and mitochondria (MnSOD). Primarily, SOD catalyzes the efficient removal of superoxide free radicals inchloroplasts as they are mainly generated in the photosystem I, during the light reaction. CAT is located in the peroxisomes of plant cells, and its main role is the elimination of H_2O_2, which is produced by the SOD reaction. Another antioxidant, APX, also can remove H_2O_2; however, it is distributed in the preoxisomes as well as chloroplasts, cytosol, and mitochondrion.Plants can induce defense responses against oxidative stress by activating the non-enzymatic antioxidants, which represent the second line of defense against ROS, hydrophilic molecules(ascorbate, glutathione) and lipophilic metabolites (carotenoids,a-tocopherol Gowayed *et al.* (2017). In addition, glutathione protects the thiol-groups of enzymes located in the chloroplast stroma and participates in the production of a-tocopherol and ascorbate Racchi (2013). Besides its role in detoxification of ROS, glutathione induces physiological responses such as the regulation of sulfur transportand expression of stress defense genes . Carotenoids are a class of phenolic compoundsdistributed in various fruits and vegetables. Theycan prevent lipid peroxidation by scavenging single oxide radical from chloroplasts Kühlbrandt *et al.* (1994).

Cadmium toxicity:

Cadmium, as a non-essential element, is one of the aggravating factors in soil salinity, which plays a major role in inhibition of plant growth by accumulation in plant. Cadmium in the plant could intervene in plant chemical synthesis processes such as ammonification, nitrification, DE nitrification, and microbiological process that affect the quantity and quantity of the crop products Cojocaru *et al.* (2016). It also leads to the generation of [e.g., “Reactive Oxygen Species (ROS)”] and oxidative stress so that it can impact on the performance of protein and lipids. Cadmium in leaf leads to leaf chlorosis Lin *et al.* (2016). Photosynthesis inhibition with the decline of pigment content, chlorophyll a, and phycobiliproteins Simek *et al.* (2016). Results indicated that salicylic acid and silicon alleviate the inhibitory effects of cadmium on maize seedlings by increasing both their chlorophyll content and fresh weight.Although individual treatments of salicylic acid and silicon reduced plants free proline, soluble sugars and cadmium uptake and lipid peroxidation rate, they improved root and shoot fresh weights in both cadmium stressed and unstressed seedlings. When combined, salicylic acid and silicon alleviated the inhibitory effects of cadmiumon seedlings significantly. Mohsenzadeh *et al.* (2011).

Lead(Pb) toxicity:

Lead as a non-redox active metal, by positioning in group 14 of the periodic table and having a low melting point is one of the important metals in a variety of industrial products, including paints, weights, ammunitions, and leaded glass. Lead is considered as an immobilized property in the soil so that plants can easily access it; however, it should be noticed how lead enters the plant body. One of the consequences of increasing lead is the production of ROS in plant cells, which can cause the replacement of essential ions in the cell and impair other processes such as cell adhesion and cell signaling Lyer *et al.* (2015). In the cell, nuclear by binding with DNA, lead can reduce the role of repairs in DNA and lead to a disturbance in mitotic stage and prolongs interface and consequently, increase the period of the cell cycle Dikilitas *et al.* (2016). Pb (lead toxicity) in plants can decrease the growth of roots and increase the roots' suberized. Pb (lead), with impact on the Reaction Centre and Antennae, decreases the efficiency of photosystem II Dao and Beardall (2016), which can negatively affect plant metabolism.The key mechanisms of Si mediated toxicity allevieation mechanisms is mainly 1) Complexation and co-precipatiation of toxic metals with silicon, 2) Imobilization of toxic metals ions, 3)Compartmentalization with vacuoles. Silicon (Si) addition protect the plant tissues from membrane oxidative damage under Pb stress, thus mitigating Pb toxicity and improving the growth of cotton plants. The results of the present experiment coincided with the conclusion that Silicon (Si) is involved in the metabolic or physiological changes in Pb stressed cotton plants (Bharwana *et al.*,2013).

Silicon and other stress interection:

Silicon can reduce the negative effects of other stresses including physical stresses (high temperature, freezing, drought, lodging, radiation,irradiation, UV) and chemical stresses (salt,nutrient imbalance, metal toxicity) in *Borago officinalis* L. Probably, because of the strengthening effects on cell wall. Silicon has indicated a significant effect on lodging especially in rice,wheat and barley by enhancing the amount of light and photosynthesis Dorairaj *et al.* (2017). Some researchers reported a highly significant role of supplied silicon in enhancing the biosynthesis of phenolic compounds under UV-B stress. The result of experiments showed that silicon application was significant in alleviating the adverse effects of UV-B.Significant advances have been made in alleviating the effects of UV-B by exogenous silicon application on soybean, wheat and maize Shen *et al.* (2014) silicon application reduced the apoplastic Mn levels in cowpea Horst *et al.* (1999). The most significant effects of silicon on metal toxicity are by reducing Cd and copper (Cu) uptake and root-to-shoot translocation by increasing metal adsorption and Zn and Mn uptake Rizwan (2012). It was revealed that silicon reduced Cd uptake by the plants as well as decreased shoot to grain translocation of Cd Adrees *et al.* (2015).

Conclusion :

The mechanism responsible for increased metal tolerance in Si-treated plants is still a matter of discussionand contradictory results have been reported.Si application shows varying response to ROS scavenging by activating the defense system plants. In doing so, the activity of antioxidant (CAT, SOD, PPO, POD, APX, GPX, and GSSH) may also oscillate depending upon the intensity of heavy metal stress and plant type. However, plants treated with Si presented not only biomass increasing but also higher metal accumulation. This clearly indicates that a silicon-mediated mechanism plays a role in alleviating the metal stress. Significant structural alterations on xylem diameter,mesophyll and epidermis thickness, and transversal area occupied by collenchyma and midvein were alsoobserved as a result of Si application. The precipitation of silica in the endodermis and pericycle of roots seemsto play an important role on the crop plantstolerance to heavy metal stress. Such results indicate that Si could beused in phytotechnologies aiming at increasing the tolerance and accumulation of metals in plants,which may become very good opurtunity to reduce heavy metals from our food grains.

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