Effects of heavy metals' toxicity on plants and enhancement of plant defense mechanisms of Si-mediation “Review"

Abolghassem Emamverdian[1], Yulong Ding[2*]

[1,2]Co-Innovation Center for Sustainable Forestry in Southern China, Nanjing Forestry University, Nanjing, 210037, China
[1]College of Biology and the Environment, Nanjing Forestry University, Nanjing, 210037, China
[2*]Bamboo Research Institute, Nanjing Forestry University, Nanjing, 210037, China
*Correspondence should be addressed to Yulong Ding, Postal address of corresponding author: NO.159, Londpan Road Nanjing, 210037, Tel: +86-25-85427318

***Abstract*—** *Today’s [e.g., “heavy metals (HMs)”] caused by anthropogenic activities have negative impacts on our environment and food productions. HMs can be classified as either essential or nonessential. A trace of essential HMs, such as Cu, Mo, and Zn, can be necessary for plant metabolism, but excess of them can harm the plant growth and development. Nonessential HMs, however, are toxic for plant metabolism and have damaging effects on enzyme activity, photosynthetic properties, cell membrane, permeability and eventually plant growth. Plants with avoidance and tolerance against stress could manage extreme HM stress in soils so that with special mechanisms, such as specific translation and metal accumulation, can elevate abiotic and biotic stress in plants. Moreover, in cells with mechanisms such as [e.g., “Metallothionein (MTs)”] (metal binding proteins) or [e.g., “Phytochelatin (PCs)”] storage and crystallization could reduce the HM stress in the cell wall, plasma membrane, cytosol, tonoplast and vacuoles. Meanwhile, the role of Si-mediation in detoxification of HMs is so bold. Si-mediation with increasing antioxidant, reducing lipid peroxidation, and increasing efficiency of photosynthetic properties elevates the HMs and other biotic and abiotic stresses in plants.*

***Keywords*— HMs, stress, cells defense mechanism, Silicon.**

Abbreviation:*HMs(heavymetals);MTs(Metallothionein);PCs(Phytochelatin);WHO(WorldHealthOrganization);ROS(ReactiveOxygenSpecies);BBYs(enrichedthylakoidsmembranes);PsII(PhotosystemII);SOD(Superoxidedismutase);CAT(catalase);APX(ascorbateperoxidase);DHAR(dehydroascorbatereductase);GR(glutathionereductase);WUE(wateruseefficiency);ELP(Euph orbia characias latex peroxidase);WCE (whole chain electron transport activity); LHC(light harvesting complex).*

I. INTRODUCTION

HMs are known as biotic stress and hazardous chemical that could affect human health by influencing the food chain and aquifers. They are, also, known as one of the reasons to inhibition of plant growth [1]. There are two types of metals in the soil: essential and non-essential. Essential HMs plays an important role in many enzyme activities as cofactor and in other protein structures which plants need them for growing and development [2,3]. However, HMs concentration is an important factor in the growth of plants so that the excess of HMs can lead to a reduction in plant growth. Heavy metals with binding to sulfhydryl group could lead to ions' substitution on protein structure [4]. In the other hand, enhancement of HMs can initiate the oxidative stress by generating ROS form oxidative stress, which in turn may disrupt the balance between pro-oxidant and antioxidant homeostasis. Additionally, observation obtained by oxidative attacking to DNA in cultured cells, and animals indicated that metal has this ability to interact with nuclear proteins and DNA [5]. Plants use a number of defense mechanisms for detoxification of toxic when encounter with abiotic stress caused by high concentration of HMs. This can help to recover and ameliorating in cells. As the first step, plants start with some avoidance and hemostasis mechanisms to prevent the onset of stress in extracellular, including binding them to micronize, cell wall, and extracellular exudates or with control efflux pumping of metals in plasma. This includes membrane and mechanisms of storage and detoxification in the vacuole and protoplasm. Among these mechanisms, the most important ones are transferring and sequestration to the vacuole, chelation mechanisms and reducing the damage heat shock proteins with renovating their [4,6]. It has been found in recent decades that Si could play an important role as one useful element in plant resistance which copes with abiotic and biotic stress and improves the plant growth [7]. In plants, silicon amplifies water-use efficiency [8], enhances cell wall rigidity [9], increases antioxidant enzyme activities, and reduces lipid peroxidation [10]. The aim of authoring this paper is to first recognize the impact of HMs on plants, and then investigate the toxicity of some non-essential HM on plants and study the plant defense mechanisms. Eventually, it is aimed to assess the Silicon as a reduction and amelioration of biotic and abiotic stresses.

II. HEAVY METAL TOXICITY IN PLANTS

HMs in plants could be due to the increase in free radicals and consequent occurrence of oxidative stress that lead to oxidation of membrane protein and lipids, or directly due to disturbance of plant activities by interacting with DNA [11]. Some of the HMs, such as Ni(nickel), Cu(copper), Zn(zinc), Fe(iron), Mn(manganese), and Mo(Molybdenum) depend on their concentration, could act as nutrient that are essential for some enzyme activities as cofactor and very beneficial for growing organisms in the plant. However, there are some other HMs that their efficiencies of the plants are not well understood; in many studies, they are known as metalloids and considered non-essential for plant growth [12,13,14]. Identification of non-essential HMs can give us a better understanding of how they operate in a different plant culture (recognition of their performance in different plants) [15] In this section, we consider three nonessential HMs including Pb(lead), Cd(Cadmium) and Hg(mercury), which have been named as the most toxic HMs in an environment[16].

2.1. Lead(Pb)

Lead as a non-redox active metal [17], by positioning in group 14 (IVA) 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 [18]. However, because of the protective role against acid and radiation, the most important application of lead is in recyclable car batteries [16]. In other hand, lead is known to be one of the most hazardous materials in the soil and the air so that a trace of lead can cause problems for the environment and human life [19,20] . In the human body, excess of Pb can cause problems in body skeleton, nervous system, circulatory, enzymatic, endocrine, and immune systems [21]. It can also seriously affect children's brain activities [22]. Having accumulation properties for hundreds of years, untapped soils can act as a reservoir of lead [23]. With the development of technology and appearing new generations of surplus-lead in smelting industry, mining [20], agricultural activities, Urbanism [24], and paints [25] lead has been turned into a serious problem for this century [20]. 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. Because the roots do not have any sites for Pb uptake, and lead would be absorbed through the root surface by carboxylic structures of mucilage uranic acids [24]. 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 [25]. 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 [26]. Pb (lead toxicity) in plants can decrease the growth of roots and increase the roots' suberized [27]. Pb (lead), with impact on the Reaction Centre and Antennae, decreases the efficiency of photosystem II [28], which can negatively affect plant metabolism.

2.2. Cadmium(Cd)

Cadmium, as a non-essential element [29], is one of the aggravating factors in soil salinity, which plays a major role in inhibition of plant growth by accumulation in plant [30]. Resources of cadmium in nature are volcanic emissions and weathering of rocks [31]. Cadmium naturally exists at trace amounts in soil (0.8-3.5 mg kg^{-1} soil); but, because of human manipulation of environment, such as mining, polluting water, and using fossil fuels, it can be observed in large quantities (up to 4-50 mg kg^{-1} soil) [32]. In fact, it turned into one of the main pollution in the soil caused by phosphate fertilizers and sewage sludge [33,8]. Since Cadmium is a mobile heavy metal that could be transferred easily between plants, investigating the effects of Cadmium in the environment is considerably important [33,34]. Because of powerful toxicity, even at low concentrations, mobility property, and simple entrance into the human food chain, Cadmium (Cd) can be named as one the most dangerous heavy metals [35,36]. Normal amount of Cd in agricultural lands is 1 mg kg^{-1} that could be increased due to human activities such as pesticides, irrigation and industrial activity [36]. Cadmium is absorbed by minerals, gets into the plants, and accumulates at different levels in plants; it, then, influences the human food chain and causes human carcinogen [37]. [e.g., “World Health Organization (WHO)”] has announced that the permitted level of cadmium in a normal human body is 70 µg [38]. Itai-Itai disease is one of the well-known diseases caused by accumulation of Cd in plant [39]. Cadmium was more toxic than chromium [40]. 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 [41]. 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 [8]. Cadmium in leaf leads to leaf chlorosis [36], photosynthesis inhibition with the decline of pigment content, chlorophyll a, and phycobiliproteins [42,43] and then reduce the plant biomass [42]. In an experiment, effect of cadmium on *P. Flagellifera* showed that the excess amount of Cd could decrease the plant growth and photosynthesis pigment and damage thylakoid membranes and then disturb the cell wall activity [43], chlorophyll content, and stomata size of Schinus molle trees [44]. In another experiment, uptaking Cu on two Cypress Varieties indicated that with increasing 100 mg kg^{-1} of Cd, the plant growth approximately decreased 37.6 % in P. *Orientalis* and 40.6 % in J. *Chinensis* [45].

2.3. Mercury (Hg)

Elemental mercury and its industrial derivatives, as a non-essential HM with high toxicity [46,47], are one of the detrimental factors in human health and plant growth [48,49]. Because of high volatility and water solubility, mercury [Hg0 (g)] is really hard to be removed [50]. Studies have shown that approximately 2320 t of Hg releases in atmosphere per year [51]. Anthropogenic activities, including smelting, mining and other industrial activities are the major sources of Hg in the environment [52,53]. However, one of the most important sources of mercury made by human activities is coal combustion and coal-fired power plants [54,55,56]. The average amount of mercury in Chinese coal is 0.22 mg/kg and in US is 0.09-0.126 mg/kg [54]. Although mercury is essential in many industrial applications, such as producing ultraviolet radiation in fluorescent lamps [57,58], but it is harmful for human health and could easily leave a negative effect on the nervous system; moreover, its development can hardly affect the renal system, immune system, reproductive system, and kidneys, especially for infants, children and pregnant women [59,60]. There are three toxic forms of mercury in the environment, including elemental mercury (Hg^0), miraculous ion (Hg_2^{2+}) and mercuric ion (Hg^{2+}) [46]. Mercury may exist in environment as gas, liquid, or solid so that it can be exposed to plant [61]. The main source of mercury in agriculture is anthropogenic activities, including pesticides, manure, lime, fertilizers and low quality urban compost [62]. Mercury in soil can be accumulated in the plant roots and then transferred to shoot, or it can be absorbed by the stomata in the leaves during the process of transpiration stream as gas [61]. In plants, mercury leads to a reduction in plant growth [62], especially in the root because of accumulation [63], disturbance in membrane structures, mineral nutrient uptake, photosynthesis, and transpiration and generation of reactive oxygen species (ROS) and oxidative stresses [62].

III. THE EFFECTS OF HEAVY METALS ON PLANT GROWTH

Plants, in the life cycle, need some essential micronutrients for growth and development; but, this issue depends on the dose and concentration of micronutrients. Trace concentration of some essential HMs would stimulate the plant growth [64] and act as a regulator and cofactor in enzyme activates [65]. A previous study on the effects of different doses of Cd (II), Cr(Chromium) (VI), Cu (II), Ni (II), and Zn (II) on the growth of the alfalfa plants (*Medicago sativa*) indicated that the seed germination significantly increased in Cd and Cr to 10 ppm, and in Cu and Ni to 20 ppm; it also showed that the shoot size increased to 14.0%, 60.0%, 36.0%, and 7.7% in Cr (VI), Cu (II), Ni (II), and Zn (II), respectively [64]. In other hand, increasing of heavy metals due to fracture makes both old and young roots to be thick and brown and decreases the length and elongation of roots; due to the important role of roots in water absorption, it consequently decreases the water absorption in plant [11]. In another experiment, effect of five HMs on seed germination and plant growth in *alfalafa* were studied [66]. The results indicated that all five heavy metals, except Zn with 40 ppm concentration, decreased the seed germination, root and shoot elongation in *alfaalfa* [66]. Shivhare and Sharma (2012) [67] investigated the effects of HMs on Georgina Wild (Dahlia). Their results indicated that increasing of HMs concentration decreases the root and shoot elongation and consequently, leads to inhibition plant growth and development [67].

IV. THE EFFECTS OF HEAVY METALS ON PLANT PHOTOSYNTHESIS

Many different studies indicated that HMs inhibit the net photosynthetic rate (Pn) and intracellular CO2 concentration [68,69]. HMs, directly (with accumulation in leaves) and indirectly, disturb stomata structure and decrease net photosynthesis and transpiration [70]. They induce alteration in chlorophyll a (chl a) and chlorophyll b (chl b) ratio, and is especially decreasing the chlorophyll content and biosynthesis [70]. Disturbing the electron transport system activities, heavy metals decrease the Photosystem II (Ps II) activities. High concentrations of heavy metals decrease the energy dissipation in reaction centers with affecting the reaction center or light harvesting complex (LHC), alternating state 1-9 state 2 transition in the LHC, and disturbance in the antenna complex [71,72]. Babu et al, (2010) investigated the effects of two heavy metals (Cr and Ag) on Cyanobacterium, Spirulina platensis. Their results indicated that heavy metals at Ps II decrease the [e.g., “whole chain electron transport activity (WCE)”] as 17% with inhibition of absorption light and energy in the reaction center and [e.g., “light harvesting complex (LHC)”] [71]. Moreover, in other studies, similar results obtained on chloroplasts, [e.g., “enriched thylakoids membranes BBYs”],thylakoid membranes and [e.g., “PhotosystemII PsII”] complexes [73,74].

V. THE EFFECTS OF HEAVY METALS ON ENZYME ACTIVITIES

According to previous studies in contaminated areas, diminishing the amount of HMs could influence the micro-organisms and enzyme activities and lead to an increase in enzymatic and microbial activities of soils [75,76]; in contrast, excess of HMs could lead to a decrease in the affluence of soil microbial community [77] and enzyme activities in soil [78,79,80]. In soil, HMs can disturb the structure, alteration, diversity, population, size and overall activity of microbial and bacterial community [81], cause an inhibition on synthesizes enzymes [81,82], decrease the bacterial species richness and consequently, change the chain and cycle of nutrients in soil. In other hand, HMs with effect on enzymes in plant restrict water and nutrient absorption by the roots, disturb the photosynthesis process, cause a morphological alteration in plants and consequently, decrease the plant growth [81]. In one study on seven different tree species at five enzymes involved in carbon, phosphorus and nitrogen cycle, including phosphates, â-glucosidase, cellobiohydrolase, chitinase, and xylosidase, HMs strongly decreased all activities of these five enzymes in soil, and also, according to tree species, in fine roots [83]. Khan et al (2007) investigated the effects of Pb and Cd on some individual enzymes such as catalase, alkaline phosphatase, dehydrogenase and found that they could significantly reduce enzyme activities. In other hand, the changes of microbial community structure can reduce the range of microorganisms and enzyme activities; this process is conducted with binging HMs to amino acids [84]. Evaluating Ni in some enzyme activities, researchers indicated that Ni decreased the enzyme activity, according to enzymes sensitively so that urease > dehydrogenases > alkaline phosphatase > acid phosphatase > catalase > arylsulphatase > β-glucosidase. This showed different reactions of enzymes to excess HMs [85]. Moreover, antioxidant enzyme activities may increase with the excess of HMs. Kumchai et al (2013) investigated the excess of Mo on cabbage seedling. Their results showed a positive effect on antioxidant enzyme activities such a [e.g., “Superoxide dismutase (SOD)”] , [e.g., “catalase (CAT)”] and [e.g., “ascorbate peroxidase (APX)”] that can be counted as plant nature reaction to excesses of HMs; this means that plants produce antioxidant enzyme activities under stress condition to overcome the cell damages [86]. As a conclusion, it could be said that HMs is the most harmful element on enzymatic activities that can be summarized to affluence of soil microbial and bacterial communities and lead to inhibition on synthesizes enzymes in soil and restrict the water and nutrient absorption by roots as well as the photosynthesis process in plants.

VI. THE EFFECTS OF HEAVY METALS ON MEMBRANE PERMEABILITY

One of the outcomes of extra HMs is the effects of HMs on the efficiency of cell membranes in plants. HMs have the ability to penetrate the cell membranes and bound with cell membranes constitutive such as proteins and phospholipids groups; They also distribute the functions of cell membranes, disrupt the transporting activities and substitution of calcium ions at essential sites, and reduce the level of plasma membrane H^+-ATPase MRNA [87] so that the availability of the substrate of the ATPase is reduced by binding with ATP [88]. One experiment showed that the permeability in root cells with K^+ efflux increased when they are exposed to excess of Cd^{2+} [89]. Evaluating the role of floc size in membrane permeability, Amiri et al (2010) concluded that excess of HMs on the pores of cake layer in the membrane and the toxic affects the sludge properties and decreases the permeability in cells so that the excess of HMs prevents the formation of larger floc and decreases the membrane permeability [90].

VII. PLANTS’ RESISTANCE MECHANISMS AGAINST HEAVY METAL STRESS

Avoidance of stress and tolerance to stress are general mechanisms of plant reactions encountering abiotic stress, such as extreme HMs in the plant. Therefore, plants induce avoidance and tolerance mechanisms against heavy metal stress with some strategies such as alternation in permeability regulation and plasma members. Additionally, plants can be detoxified with mechanisms such as metallothionein (MTs) (metal binding proteins) and phytochelatin (PC) [91]; Phytochelatin (PC) mechanism in Cytosol is one of the best detoxification mechanisms under stress conditions [92]. In the cell, plants accumulate the heavy metals with special mechanisms. However, in high concentrations, heavy metals are transferred to the cytoplasm and removed rapidly, so that cations are broken into complex compounds by Thiol-containing molecules. Tonoplast decreases the heavy metal efflux to cells with some permeability mechanisms. Then, in the vacuole, remaining heavy metals will be stored and converted to crystal. Finally, the heavy metal toxicity is decreased [93] (Fig 1). This mechanism (accumulation and transport of HMs to cytoplasm), which is expressed as an indicator in face with extra heavy metals, keeps the gate of cells open [93]. The total tolerance ability of HMs of plants depends on plant species tolerance**.** Some species can prevent penetrating of excess heavy metal to aerial part; some species also accumulate the excess of HMs in their above ground tissue that could be toxic to most plants [94]. Meanwhile, the role of some mediation in raising the defense mechanism of plants against stress is important that we address it below.

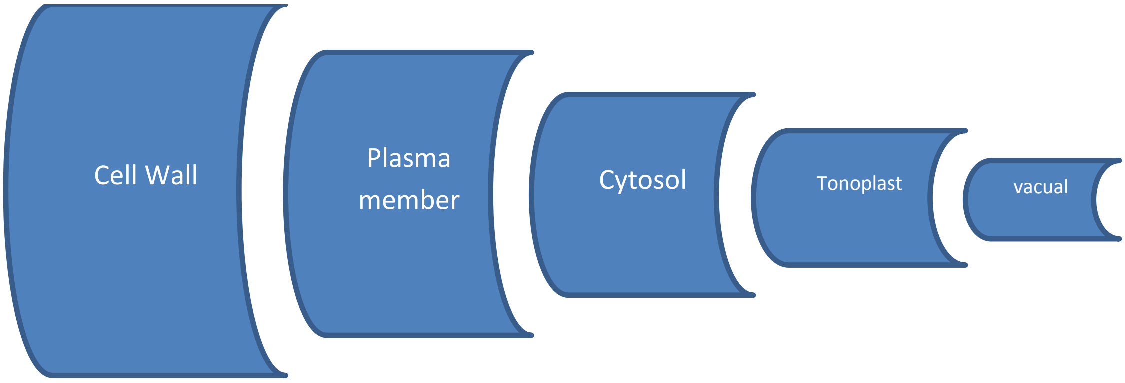

FIG 1: PLANT CELL MECHANISMS TO HMS STRESS: CELL WALLS ARE THE FRONT LINE OF HMS STRESS SO THAT WITH MECHANISMS SUCH AS SEDIMENTATION, BIND TO PECTIN CAN ELEVATE HMS STRESS. IN PLASMA MEMBER, PLANTS, WITH REGULATION OF METAL TRANSPORTATION, REDUCE THE INFLUENCE OF HMS ON THE CELL, AND THEN IN CYTOSOL, REMOVE THE COMPLEXION AND CAUSE A RAPID COMPLETION AND RAPID REMOVAL FROM CYTOSOL. TONOPLAST DECREASES THE HEAVY METAL EFFLUX TO CELLS WITH SOME PERMEABILITY MECHANISMS, AND FINALLY, IN VACUOLE, REMAINING HEAVY METALS WILL BE STORED AND CONVERTED TO CRYSTAL.

7.1. Si-mediated ameliorate plant tolerance against to stress

Silicon is one of the most important elements in the soil [95,96] taking 28% of the total earth surface [97.98]. It is considered as an important fertilizer component to ameliorating effect on plant growth in abiotic and biotic stress [95,96,97,99,100]. In plants, roots can take Si with silicic acid form $Si(OH)_4$ [101,102,103,104] with doses of 0.1 to 0.6 mmol L^{-1} in the soil [102] that is translocate to shoot by transpiration flow in the xylem [9], and depending on different cultivars, plants have an ability to accumulate Si between 0.1% to 10.0% Si (dry weight) [101]. There are many mechanisms to reduce HMs stress by Silicon, including HMs armature binding to the wall of Sully [95], stimulation of enzyme and non-enzyme, antioxidant that consequently decrease the lipid and H_2O_2 [95,102] peroxidation, and the positive variety of sub-cellular distribution of HMs [95]. Si-mediation improves the quantity and quality of crops. In one study, Si promotes the photosynthetic rate and chlorophyll content with positive alternation in leaf anatomy in banana [105]. Gottardi et al,(2012) investigated the effect of silicon on corn salad (*Valerianella locusta* (L.) Laterr). They found that it can increase edible yield, quality of crops and shelf life [98] Si-mediated alleviation of abiotic and biotic stresses including HMs, salinity, drought, disease, chilling and freezing stresses [106,103] that summarized below.

7.1.1. Si-mediated against heavy metal stress

Si with the rising of pH solution and inhabitation of metal Phyto-availability [97] influences in bioavailability metals and regulates them [99]. Stimulating antioxidant enzyme, Si reduces the necrotic spots caused by superoxide anions and free radicals in the leaves of both Zn and Mn plants [107]. On the other hand, Si improves the growth and development of cotton crop exposed to Zn stress by limiting Zn bioavailability and oxidative damage [97]. Moreover, the role of Si in the alleviation of iron soybean and cucumber plant growth is revealed by reducing the iron choruses and impact of iron distribution [99]. Si in the cell wall with the effect of cation binding capacity decreased concentration of Mn in apoplastic in cowpea [106]. Reduction of Mn toxicity in cucumber is happened by Si because reduction of lipid peroxidation is caused by stimulation enzymatic (e.g. SOD, APX, DHAR and GR) and non-enzymatic antioxidants (e.g. Ascorbate and glutathione) [106]. But , effect of Si on HMs changes according to cultivars and tissues [102] that can attribute to different Si uptake by the roots [101]. Evaluating the role of Si on uptake and translocation of arsenic and entry into the fruit indicates that different cultivar of tomato can show the opposite reaction to a combination of silicon [108].

7.1.2. Si-mediated against salt stress

Salt stress is one of the agriculture soil problems that have an adverse effect on plant growth by inducing oxidative stress [109]. Si-mediation can elevate the salt stress in plant by improving the antioxidant enzymes, decreasing lipid peroxidation, reducing permeability of the plasma membrane of leaf cells, ameliorating the ultra-structure of chloroplasts [110], improving shoot plants, and increasing gas exchange rate such as stomata conductance, net photosynthetic rate, and transpiration [111]. Additionally, Si can elevate the salt stress with apoplastic sodium absorption to adjust the stomata and spaces [112]. A previous study revealed that application of Si is beneficial in improving the salt tolerance of tomato, grass, and *Spartina densiflora* plants with balance in mineral nutrient, [e.g.,"water-use efficiency (WUE)"] and increasing photosystem properties [96,113]. The result of another study indicated that application of Si reduces the effect of salt stress on potato with conservation plant water content due to increasing water-use efficiency [114]. The results of a study on cucumber showed that Si-mediated amelioration salt stress with increasing antioxidant defense enzyme and reducing [e.g., "Euphorbia characias latex peroxidase (ELP)"] and H2O2 [115]. Later, in another study, it is shown that Si can improve the salt tolerance in barley (*Hordeum vulgare* L.) by increasing the antioxidant enzymes and consequently, decreasing the lipid peroxidation [110].

7.1.3. Si-mediated against disease stress

Si plays an important role in alleviates plant disease and their control [7] and prevents the entry of fungi and disease to plants [112]. There are two mechanisms for Si against disease: the first is that Si forms a cuticle-Si double layer and prevents the influence of fungi on plants; the second is that Si acts as one adjuster host resistance to pathogens [101]. It is shown in a study that Si decreased the spread of root-rot pathogen *Pythium aphanidermatum* in bitter gourd [116]. Si can rise the ability of plants in preventing the leaf and neck blast, sheath blight, brown spot, leaf scald, and stem rot in rice [101]. Si decreases the brown rust incidence in sugarcane with increasing the leaf Si concentrations [117].

7.1.4. Si-mediated against drought stress

The role of silicon in plant is known as one osmoregulation to regulate the water deficit, which is related to the efficiency of photosynthesis and antioxidant enzymes in plants [118]. Silicon in the leaf surface reduces the loss of water by transpiration, and thus, reduces the drought stress [116]. Moreover, Si with a cooling mechanism by mid-infrared thermal emission of Si can adjust the leaf temperature [116]. Drought stress usually reduces the of crops yielding with interfacing in photosynthetic pigments, proteins, lipids, and some enzyme activities and leads to an oxidative damage in plants. The results of another study on wheat (*Triticum aestivum* L.) showed that Si can elevate drought stress by increasing the antioxidant defense mechanism and consequently, increase the photosynthesis properties [119]. Si concentration has a positive impact on the improvement of water resources in rice plant [120] and seed germination in tomato under water deficit stress by enhancing the antioxidant defense [121]. Generally, Si is not categorized as one essential heavy metals ; however, that is a beneficial element for improving the plant growth and development. It can also be expressed that Si-mediated is one proper application to raise the plant defense mechanism in confronting with biotic and abiotic streets [101].

VIII. CONCLUSION

HMs are one of the most important abiotic stresses that inhibit the growth and development in living organisms, lead to an early senescence of them [122], and menace safe food product for human over the world [123]. In plants, the excess amount of HMs leads to some symptoms such as necrosis, chlorosis, alterations of plants' phenotype, and genotype, causes an oxidative stress, and subsequently reactivates oxygen species (ROS) so that they stimulate the plant defense mechanism such as increasing antioxidant enzymes and non-enzyme activities [124]. Hence, that is counted as the most important defense mechanism of plants against stress for cell protects [125].

Plants, in response to HMs, follow three different strategies: 1- metal excluders: it covers a majority of mechanisms, including a large group of plants in which plants prevent the HMs stress by limiting the translocation of HMs into plant aerial parts; 2- metal indicator: plant is one indicator of soil HM that accumulates in biomass and other parts of plant; 3- metal accumulation: plants are counted as an accumulator in soil so HMs transudate and accumulate in plant tissue [126].

In cells, using strategies such as metal binding to cell wall and chelation, transforming HMs to low levels, and eventually accumulation and crystallization of them, plants could detoxify the HMs stress [127].

Si-mediation can help plant biomass production and plant growth [128]. One of the avoidance mechanisms of Si-mediation in the root is to reduce the uptake of HMs (Cd) with increasing the root oxalate exudation by enhancing the number of root tips [129].But, the major role of Si, when encounters with abiotic stress, is the elevation of the plant resistant by increasing the antioxidant enzyme activity [130].Si-mediation in cells decreases the toxic concentrations caused by HMs, symplast, apoplast, and incensement Si-absorbed in cell walls, and limits the root to shoot HMs translocations [131].

Generally, excess of HMs in agricultural soil caused by anthropogenic activities has made serious problems on the way to boost the agricultural products and improve their quality. In recent centuries, numerous studies carried out by researchers to alleviate and ameliorate the HMs toxicity in plants, which have revealed new ways for research communities to understand

and solve this problem. Si-mediation is one of the beneficial elements in stress conditions that helps to increase the efficiency of antioxidant enzyme activity. In this study, we tried to identify some non-essential elements and express some plant mechanisms caused by Si-mediation in coping with abiotic and biotic stress.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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