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Review on Role of Salicylic Acid in the Alleviation of Cadmium Induced Damage in Plants.

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ABSTRACT

Cadmium is most toxic pollutant in the environment, originating mainly from rapid industrial processes and application of phosphate fertilizers, which causes a serious risk to plants and animals. It is easily absorbed by the plants, resulting in apparent toxicity symptoms, including retardation of the growth, chlorosis of leaf, root and leaf necrosis, altered structures and ultra-structures, inhibition of photosynthesis and finally cell death. Therefore alleviation of Cd toxicity in plants is the major aim of plant research. In this context, salicylic acid (SA) is a ubiquitous plant phenolic compound which could play an important role in mitigating the uptake of the Cd ions and providing immunity to plants against the heavy metal stress. SA alleviates the Cd toxicity by enhancing their resistance capacity of contaminated plants to metal stress. Furthermore, SA is considered as a promising signal molecule for improving the efficiency of phytoremediation and growing safe crops in metal polluted areas. This review presents an overview on the damage induced by the Cd in plants, role of exogenous and endogenous application SA in alleviating Cd toxicity and also it could have an effect on phytoremediation of Cd from contaminated soils are discussed.
Keywords: Alleviation, Cadmium toxicity, Phytoremediation, Salicylic acid.

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INTRODUCTION

Cadmium is most toxic heavy metal, non-essential for plants which enters the environment from industrial processes and phosphate fertilizers. This phosphate fertilizers lead to the accumulation of Cd in agricultural soils[1]. From this soil, cadmium can easily absorbed by the plant roots [2] which induces various morphological, physiological, biochemical and structural changes, leading to the phytotoxicity in plants, it is the most visible symptom which includes leaf chlorosis, reduction in root and shoots growth and eventually causes the leaf or root necrosis. Cd even at low concentration can lead to the death of the plant [3]. Because of the accumulation of Cd in different parts of the plants like edible leaves, seeds and fruits [4,5], it entering in to food chain and becoming a serious threat to the human health [6,7]. Due to this exposure of plants to Cd stress causes the structural and ultra structural changes in plants [8,9] i.e., inhibition of photosynthesis, leaf transpiration [10] and disturbance in mineral nutrition. Cd also causing adverse effects on the prostate, liver, kidneys, heart and vascular organs in human beings[11]. Moreover it is also having carcinogenic, mutagenic and teratogenic effects [12]. Therefore alleviating the toxicity of Cd in plants is a major aim of current plant research. In plants, several vital ways have been adopted to alleviate Cd toxicity and the modulation of plant growth regulator levels has been extensively researched. Plant hormones such as abscisic acid (ABA), gibberellic acid (GA) [13,14], nitric oxide (NO) and salicylic acid (SA) [15] that play a crucial role in the survival and adaptation of plants growing under Cd stress.

Salicylic acid, a plant growth regulator and ubiquitous plant phenolic compound which plays an important role in regulation of plant growth development and involved in both local and systemic plant defense responses in plants [16]. SA mediates some regulating responses to heavy metal stress mainly Cd stress. Pretreatment of SA can alleviate Cd toxicity in barley [17] and maize plants [18]. Exogenous application of salicylic acid (SA) can leach and immobilize Cd in soils [19]. Salicylic acid (SA) acts as a signaling molecule and involved in the expression of specific responses in plants to biotic and abiotic stresses [6,20] which provides protection against the Cd stress [21]. So alleviation of Cd toxicity by SA involves various diverse processes such as reduction of uptake and accumulation of Cd in plant organs [22], protection of stability and membrane integrity [23] decreasing the accumulation of hydrogen peroxide (H_2O_2) [15], interacting with other plant hormones [24], scavenging ROS and enhancement of antioxidant defense mechanism. [25,26], improving the photosynthetic capacity [27], and up regulating heme oxygenase [28]. Moreover, SA may also involved in the expression of several important genes which are responsible for resistance to Cd and have evolved a variety of mechanisms to reduce the stress that involves the complex formation and sequestration of Cd [29], reduction of toxic metal to less toxic form, generation of the oxidative stress response, reduced membrane permeability and direct removal of metal [30]. There is evidence which suggests that SA is capable of reducing/detoxifying Cd toxicity and could be a promising tool in increasing the phytoremediation efficiency [31]. In this review the discussion has made about the toxicity of Cd in plants and influence of SA on Cd induced stress in plants and also focused on the alleviation of Cd toxicity by using potential mechanisms.

Toxicity of Cd in plants

Most of the plants are toxic to Cd even at very low concentration i.e., 5-10µg g^{-1}dry weight in leaves [3]. A number of changes that have been reported in plants due to the toxicity of Cd such as decreased uptake of nutrients [32], interaction with the water balance of the plant, changes in nitrogen metabolism [33], and inhibition of stomatal opening [34]. Photosynthesis also inhibited due to the exposure of Cd through the effects of chlorophyll metabolism and chloroplast structure [35]. Both photosystem II activity and enzymes of photosynthetic carbon metabolism are also getting affected [36]. Earlier studies have shown that there is a maximum reduction in the photochemical efficiency of photosystem II due to Cd which results in the increased impairment in the net CO2 assimilation rate [37,38]. This may cause the destruction of chloroplast structure, photosynthetic pigments and chlorophyll destruction as a consequence of substitution of Mg in both Chl *a* and *b* pigments [39]. Cd exposure also causes an increase in the lipid peroxidation and alterations in antioxidant enzyme system [40,32]. The toxicity of Cd is also known to cause alterations in the functionality of the membranes affecting lipid composition [41] and this can affect some enzymatic activities associated with membranes such as H^+-ATPase [42].

Nutrients are essential for the proper growth and development of the plants. Exposure of cadmium causes the uptake and transport of nutrients which leads to the reduction of essential mineral nutrients in plants like phosphorous (P), calcium (Ca), magnesium (Mg), iron (Fe) and potassium (K) [43]. All these aspects suggest that in plants the interference of Cd may affect the plasma membrane's permeability and altering the nutrient composition.

At cellular levels, Cd shows negative effects which results in the oxidative stress in plant cells and causes the production of reactive oxygen species (ROS) [44], including the superoxide anion (O_2^-), hydroxyl radical ($^{\cdot}OH$), H_2O_2 and singlet oxygen (O_2), and cause damage to many biological macromolecules [45]. Plant has defense mechanism against ROS which cause the scavenging of ROS by antioxidant enzyme system. Because of the exposure of Cd to plants can cause the disruption of antioxidant enzymes and balance between production and elimination of ROS which leads to the cell death [46,47]. Furthermore, this oxidative damage could cause destruction of DNA/Protein and sphingolipids and ultimately results in the cell death [48] (Fig 1).

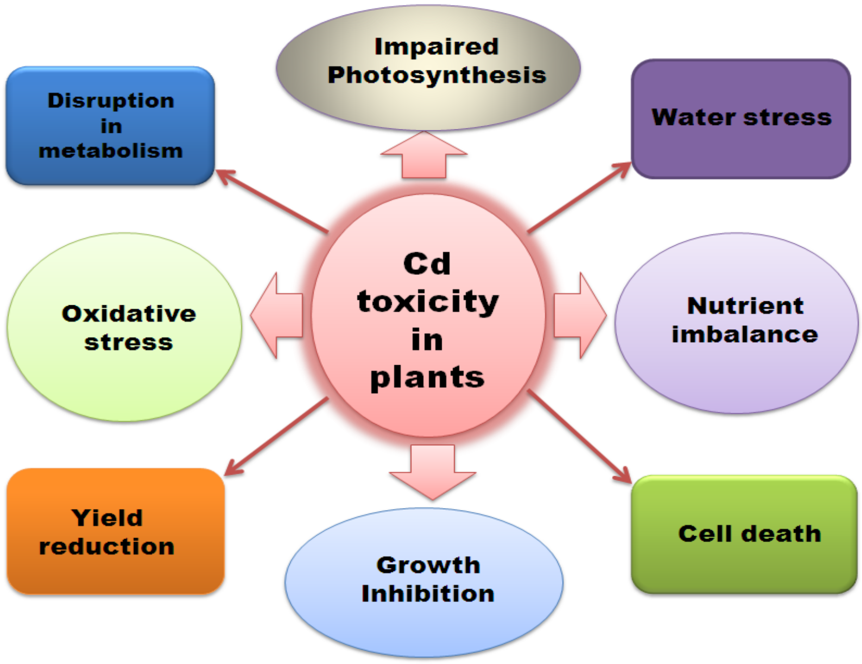

Figure 1: Effect of cadmium toxicity in plants

Alleviation of Cd toxicity in plants by SA

In many plant species, SA has role in improving their tolerance to heavy metal stress that mainly includes Cd [6]. SA could supply the plant resistance to Cd toxicity by supplementing the nutrients such as Mg, P, Fe and Ca to stressed plants [49]. This helps in the improved growth and health of the plants. Exogenous application of SA reduces the symptoms in plants which are caused by the Cd treatment in barley, soya bean, maize, pea, rice and other plants. The symptoms include decreased leaf fresh weight, gradual decrease of height and length of root and plants showed necrotic symptoms. By presoaking with SA, these symptoms do not appear. Cd exposure causes the decreased phytochelatin synthase activity (PCS) in the roots and increased phytochelatin synthase and glutathione reductase (GR) activities in maize leaves. Application of SA before Cd treatment may reduce the Cd-induced damage and have an effect on the phytochelatin composition [50].

In addition to the exogenous application of SA ameliorated the plants in maintaining the improved growth [51], an endogenous application of SA caused the regulation of Cd-induced glutathione synthase (GSHS)-like gene from *Lycium chinense* [52]. Endogenous application of SA may function as signaling molecule which increases Cd-induced oxidative damage in plants. It has been reported that pre-treatment of wheat seeds with SA facilitate the effects of Cd-induced heavy metal stress through enhanced reactive oxygen species (ROS)-scavenging enzyme activities [25]. Hence the current reports available for the involvement of SA in ROS-signaling and modulation of defense responses. For this both exogenous and endogenous SA were showed to play roles in plant metabolism during defense responses [53,54]. Moreover, it has evidenced that the involvement of signaling pathway in tolerance mechanisms to rhizotoxicities of Cd in *Arabidopsis thaliana* [55].

Protection mechanism against cadmium induced oxidative stress by SA

The exposure of Cd to the plants is associated with the production of oxidative stress which resulted in the protein carbonylation [56], lipid peroxidation [19], and generation of ROS [24]. Cd could also cause the inhibition of antioxidant enzymes and depletion of glutathione. Detoxification mechanism is involved in scavenging the ROS by activating antioxidant enzyme system. SA is involved in scavenging the ROS by detoxification mechanism and it is a promising approach to protect plants from serious effects of Cd stress [57]. Both exogenous and endogenous application of SA could alleviate ROS which include singlet oxygen ($^1O_2$), hydroxyl radicals ($^{\cdot}OH$), superoxide anion (O_2^-) and hydrogen peroxide (H_2O_2). An increase in the activities of antioxidant enzymes has observed in plants after treatment with SA, the enzymes are ascorbate, glutathione peroxidase (GPX), superoxide dismutase (SOD) and catalase (CAT) that are involved in the protection of plants from ROS and stimulating the immune system [58]. These antioxidant enzymes clear excess ROS; maintain balance of active oxygen species and protecting the membrane's structure. The application of SA exogenously increased the activities of POD, SOD and CAT in Cd-induced plants such as maize, wheat and rice. In addition the accumulation of ROS can be indirectly decreased by enhancing SOD, CAT and APX activities when treated with SA [59,60,61]. Among all the enzymes, SOD is most resistant protein produced in response to stress which catalyzes the conversion of superoxide anion to $O_2^{\cdot-}$ and H_2O_2 [62,63]. Some reports showed that treatment of SA can increased the levels and activities of CAT in rice roots and wheat leaves [64].

Regulation of antioxidant metabolism under cadmium stress by salicylic acid

The treatment with SA could alleviate the deleterious effects of Cd stress in *Triticum aestivum* [51] and in *Oryza sativa* via enhancing the antioxidant enzyme activities including SOD, APX, GPX and GR [65]. The regulation of these enzymatic and non-enzymatic antioxidant enzymes caused due to the uptake of Cd by SA, this suggests the involvement of different signals and SA-enhanced Cd tolerance [66]. Some reports showed that the redox active compounds like ascorbate and glutathione involved in the maintenance of homeostatic balance and protect the plants from Cd stress [67,68,69]. The transcript levels of genes encoding GSH synthesize (GSHS) could be regulated by the application of SA. This enzyme increased when endogenous application of SA in Cd tolerance through the regulation of LcGSHS transcript expression levels [52]. There is an improvement in the Cd tolerance and photosynthetic efficiency in *Cannabis sativa* by increasing in the activities of both POD and SOD [70]. Application of SA facilitated an increase in the activity of SOD through an enhancement of Ca^{2+} in shoots and an increase in H_2O_2 which resulted in the stimulation of many antioxidant enzyme activities and finally leading to the reduction in the levels of intracellular ROS [71]. An alleviation of Cd toxicity by Haem Oxygenase (EC 1.14.99.3), HO-1-mediated and SA-dependent signaling has observed in plants and showed an up-regulation in the antioxidative behavior in root tissues [28].

Phytoremediation technologies by SA

Phytoremediation is a process referred as botanical bioremediation that uses green plants to decontaminate air, water and soil. In order to phytoremediate Cd contamination in soils, an involvement of plant defense activators are required to clean up. So, SA showed many positive effects on plants by enhancement of phytoremediation technologies and various mechanisms have also been reported [72]. Involvement of SA in phytoremediation has showed by comparing both dye contaminated soil and remediated soil; the results revealed that there is significant decrease of SA in dye contaminated soil than in remediated soil. By this it is concluded that SA is decreased before remediation and enhanced after remediation in both *Vigna radiata* roots and leaves [73]. Most of the studies demonstrated that application of SA can enhance Cd tolerance in wide range of plant species [74, 75] and play an important role in sequestration and chelation of Cd [17]. Many evidences have positively concluded that the role of both exogenous and endogenous SA are decisive in plant responses toward heavy metal stress, but their role in phytoremediation are still ambiguous and further studies are required.

Future Prospects

Cadmium toxicity in plants showed complex changes at physiological, biochemical and molecular levels. The main symptoms included the alterations in photosynthesis and transpiration processes in plants. However, several strategies have developed to alleviate Cd toxicity in plants. SA is one which could alleviate the Cd stress by using possible potential mechanisms. Earlier reports have revealed that, the role of both exogenous and endogenous application of SA in reduction of effects of Cd toxicity in plants. The receptor proteins for SA have been reported, but they are diverse and further purification and identification is needed and because of having high efficiency, low cost, less toxicity SA has showed a broad application in agriculture technology. But still there are many gaps in understanding the basic mechanisms that control Cd toxicity by SA. Several reports suggest the toxicity of Cd and their alleviation by SA, is of great importance to study the mechanisms of SA-mediated resistance to Cd stress in plants. So further studies have to be done on various molecular mechanisms using advanced genetic and proteomic approaches in future research.

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