Cadmium

Title	*Selenium* mitigates cadmium-induced oxidative stress in tomato (*Solanum lycopersicum* L.) plants by modulating chlorophyll fluorescence, osmolyte accumulation, and antioxidant system.
Author Name	Mohammed Nasser Alyemeni, Mohammad Abass Ahanger, Leonard Wijaya, Pravej Alam, Renu Bhardwaj, Parvaiz Ahmad
Journal Name	Protoplasma
Year	2017
Volume & Issue	
Pages	1-11
Abstracts	Pot experiments were conducted to investigate the role of selenium in alleviating cadmium stress in *Solanum lycopersicum* seedlings. Cadmium (150 mg L^{-1}) treatment caused a significant reduction in growth in terms of height and biomass accumulation and affected chlorophyll pigments, gas exchange parameters, and chlorophyll fluorescence. Selenium (10 μM) application mitigated the adverse effects of cadmium on growth, chlorophyll and carotenoid contents, leaf relative water content, and other physiological attributes. Lipid peroxidation and electrolyte leakage increased because of cadmium treatment and selenium-treated plants exhibited considerable reduction because of the decreased production of hydrogen peroxide in them. Cadmium-treated plants exhibited enhanced activity of antioxidant enzymes that protected cellular structures by neutralizing reactive free radicals. Supplementation of selenium to cadmium-treated plants (Cd + Se) further enhanced the activity of superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and glutathione reductase (GR) by 19.69, 31.68, 33.14, and 54.47%, respectively. Osmolytes, including proline and glycine betaine, increased with selenium application, illustrating their role in improving the osmotic stability of *S. lycopersicum* under cadmium stress. More importantly, selenium application significantly reduced cadmium uptake. From these results, it is clear that application of selenium alleviates the negative effects of cadmium stress in *S. lycopersicum* through the modifications of osmolytes and antioxidant enzymes.
Keywords	*Solanum lycopersicum* , Cadmium , Growth , Chlorophyll fluorescence , Proline , Lipid peroxidation , Antioxidants , Selenium

Title	**Uptake, sequestration and tolerance of Cadmium at cellular levels in the hyperaccumulator plant species Sedum alfredii**
Author Name	Shengke Tian Ruohan Xie Haixin Wang Yan Hu Dandi Hou Xingcheng LiaoPatrick H. Brown Hongxia Yang Xianyong Lin John M. Labavitch
Journal Name	*Journal of Experimental Botany*
Year	2017
Volume & Issue	68 Issue 9
Pages	2387-2398
Abstracts	*Sedum alfredii* is one of a few plant species known to hyperaccumulate cadmium (Cd). Uptake, localization, and tolerance of Cd at cellular levels in shoots were compared in hyperaccumulating (HE) and non-hyperaccumulating (NHE) ecotypes of *Sedum alfredii*. X-ray fluorescence images of Cd in stems and leaves showed only a slight Cd signal restricted within vascular bundles in the NHEs, while enhanced localization of Cd, with significant tissue- and age-dependent variations, was detected in HEs. In contrast to the vascular-enriched Cd in young stems, parenchyma cells in leaf mesophyll, stem pith and cortex tissues served as terminal storage sites for Cd sequestration in HEs. Kinetics of Cd transport into individual leaf protoplasts of the two ecotypes showed little difference in Cd accumulation. However, far more efficient storage of Cd in vacuoles was apparent in HEs. Subsequent analysis of cell viability and hydrogen peroxide levels suggested that HE protoplasts exhibited higher resistance to Cd than those of NHE protoplasts. These results suggest that efficient sequestration into vacuoles, as opposed to rapid transport into parenchyma cells, is a pivotal process in Cd accumulation and homeostasis in shoots of HE *S. alfredii*. This is in addition to its efficient root-to-shoot translocation of Cd.
Keywords	Cadmium, Fluorescence microscopy, localized, micro X ray fluorescence, protoplasts, tolerance, Vacuole

Title	Salicylic acid-induced protection against cadmium toxicity in wheat plants
Author Name	F.M.Shakirova,Ch.R.Allagulova,D.R.Maslennikova,E.O. Klyuchnikova,A.M.Avalbaev,M.V.Bezrukova
Journal Name	Environmental and Experimental Botany
Year	2016
Volume & Issue	Volume 122
Pages	19-28
Abstracts	We have studied the influence of pretreatment of wheat seedlings (*Triticum aestivum* L.) with 50 μM salicylic acid (SA) on plant resistance to subsequent action of 1 mM cadmium acetate. SA pretreatment decreased the extent of detrimental effect of cadmium on wheat plants, as judged by the decline in the level of stress-induced accumulation of MDA and electrolyte leakage. Furthermore, SA-pretreatment contributed to maintenance of growth characteristics of wheat seedlings at the level close to the control under stress conditions and to acceleration of growth recovery during post-stress period. Detected defense effect of SA may be due to a decline in the amplitude of cadmium-induced accumulation of abscisic acid (ABA) and to reduced fall of indoleacetic acid (IAA) and cytokinins (CK) in stressed plants. In the course of one day treatment, SA activated phenylalanine ammonia-lyase (PAL), the key enzyme of lignin biosynthesis, in roots of seedlings under normal growth conditions contributing to the strengthening of carrier functions of cell walls. This assumption is supported by the data showing significant decline in cadmium accumulation in SA-pretreated Detected defense effect of SA may be due to a decline in the amplitude of cadmium-induced accumulation of abscisic acid (ABA) and to reduced fall of indoleacetic acid (IAA) and cytokinins (CK) in stressed plants. In the course of one day treatment, SA activated phenylalanine ammonia-lyase (PAL), the key enzyme of lignin biosynthesis, in roots of seedlings under normal growth conditions contributing to the strengthening of carrier functions of cell walls. This assumption is supported by the data showing significant decline in cadmium accumulation in SA-pretreated
Keywords	Abscisic acid, Cadmium stress, Dehydrins, Hormonal balance, Phenylalanine ammonia-lyase, Lignin deposition, Plant growth, Salicylic acid Wheat (*Triticum aestivum* L.)

Title	**Modulation and significance of nitrogen and sulfur metabolism in cadmium challenged plants**
Author Name	M. Iqbal R. Khan,Noushina Iqbal,Asim Masood,Mohammad Mobin,Naser A. Anjum
Journal Name	Plant Growth Regulation
Year	2016
Volume & Issue	78, Issue1
Pages	1–11
Abstracts	As a result of rapidly increasing anthropogenic activities, input of varied metal (loids) such as cadmium (Cd) to worldwide agricultural soils and its subsequent accumulation, and obvious toxicity in plants are increasing. The role of mineral nutrients in the mitigation of Cd-accrued consequences in plants has been credibly suggested. In isolated studies, two essential mineral nutrients such as nitrogen (N) and sulfur (S) have been reported to minimize Cd-impacts in plants, and improve overall plant growth, metabolism and productivity under Cd-exposure. However, the information on the significance of N and S metabolism, and also on cross-talks on the coordination therein in Cd-challenged plants is lacking. Given the highlighted lacunae, in the light of recent research outcomes, the present review attempts to: (a) overview Cd in soil, and its major toxicity and mitigation avenues in plants, (b) appraise Cd-mediated modulation of N and S metabolism, (c) summarize the role of exogenously-sourced N and S for the mitigation of Cd toxicity, (d) critically discuss the significance of coordination between N and S metabolism for Cd-impact-mitigation, and finally to (e) highlight the major aspects to explore in the current context. The literature appraised herein suggests that a fine coordination among major pathways of N and S assimilation can enhance defense metabolites and enzymes that in turn can strengthen overall defense system, and efficiently mitigate Cd-impacts in plants. However, efforts are required to get more insights into the mechanism(s) of (co)regulation of sulfate and nitrate assimilation at the molecular level. Additionally, molecular approaches should be narrowed to enhance the production of thiols, and their products in plants through manipulating major enzymes involved in sulfate and nitrate assimilation in plants under Cd-challenged environment.
Keywords	Cadmium-phytotoxicity, Nitrogen metabolism, Sulfur metabolism, Plant-cadmium tolerance

Title	Effects of Exogenous Spermidine on Cell Wall Composition and Carbohydrate Metabolism of *Marsilea* Plants under Cadmium Stress
Author Name	Kingsuk Das, Chiranjib Mandal, Nirmalya Ghosh, Sidhartha Banerjee, Narottam Dey and Malay Kumar Adak
Journal Name	J Plant Physiol Pathol
Year	2014
Volume & Issue	2 Issue 3
Pages	
Abstracts	In an experiment to detect the cellular changes of carbohydrate content and its related enzymatic activities, a study was undertaken with Marsilea minuta L., an aquatic fern species in simulated condition of cadmium (Cd) toxicity. From the varying doses of Cd (0, 50, 100 and 200 μM) and supplemented with spermidine (2 mM), it revealed that plants were suffered from accumulation of total carbohydrate in a dose-dependent manner under Cd stress. Maximum depletion of carbohydrate content was 58% with respect to control which was retrieved by 1.42 fold with spermidine application. In a similar manner, plants were also affected with starch, total reducing sugar content by 42% and 63.04% respectively over the control. The fall in both starch and total reducing sugar were retrieved by plants by 1.32 fold and 1.52 fold, respectively
Keywords	*Marsilea minuta*; Cadmium; Carbohydrate metabolism; Amylase

Title	**Cadmium Toxicity in Plants and Role of Mineral Nutrients in Its Alleviation**
Author Name	Rahat Nazar, Noushina Iqbal, Asim Masood, M. Iqbal R. Khan, Shabina Syeed, Nafees A. Khan
Journal Name	American Journal of Plant Sciences
Year	2012
Volume & Issue	3
Pages	1476-1489
Abstracts	Cadmium (Cd) is a toxic heavy metal that enters the environment through various anthropogenic sources, and inhibits plant growth and development. Cadmium toxicity may result from disturbance in plant metabolism as a consequence of disturbance in the uptake and translocation of mineral nutrients. Plant nutrients and Cd compete for the same transport-ers and, therefore, presence of Cd results in mineral nutrients deficiency. The optimization of mineral nutrients under Cd stress could reduce Cd toxicity by greater availability at the transport site resulting in reduced accumulation of Cd, and could also alleviate Cd-induced toxic effects by enhancing biochemical reactions and physiological processes in plants. In the present review the role of plant macro, micro and beneficial elements in alleviating Cd stress in crop plants is discussed.
Keywords	Antioxidant Enzymes; Cadmium Toxicity; Mineral Nutrition; Oxidative Stress

Title	**Unravelling cadmium toxicity and tolerance in plants: Insight into regulatory mechanisms**
Author Name	Susana M. Gallego, Liliana B. Penaa,b, Roberto A. Barciaa, Claudia E. Azpilicueta, Maria F. Iannonea, Eliana P. Rosalesa, Myriam S. Zawoznika, Maria D. Groppa, Maria P. Benavides,
Journal Name	Environmental and experimental botany
Year	2012
Volume & Issue	83
Pages	33–46
Abstracts	The occurrence of heavy metals in soils may be beneficial or toxic to the environment. The biota may require some of these elements considered essentials (like Fe, Zn, Cu or Mo) in trace quantities, but at higher concentrations they may be poisonous. Due to the difficulty in controlling environmental metal accumulation, organisms have to cope with exposure to unwanted chemical elements, specially those considered biologically nonessential. Cadmium (Cd) belongs to this latter group. The effect of Cd toxicity on plants has been largely explored regarding inhibition of growth processes and decrease of photosynthetic apparatus activity. This article reviews current knowledge of uptake, transport and accumulation of Cd in plants and gives an overview of Cd-detoxification mechanisms, Cd-induced oxidative damage and antioxidant defenses in plants. It also presents a picture of the role of reactive oxygen and nitrogen species in Cd toxicity; signalling and gene regulation are topics critically discussed
Keywords	Cadmium; Heavy metals; Oxidative stress; Metal toxicity; Signalling; Gene regulation

Title	**Oxidative post translational modifications of proteins related to cell cycle are involved in cadmium toxicity in wheat seedlings**
Author Name	Liliana B. Pena, Roberto A. Barcia, Claudia E. Azpilicueta, Andrea A.E. Méndez, Susana M. Gallego
Journal Name	Plant Science
Year	2012
Volume & Issue	196
Pages	1 - 7
Abstracts	Abiotic stress is greatly associated with plant growth inhibition and redox cell imbalance. In the present work, we have investigated in which way oxidative posttranslational modifications (PTM) of proteins related to cell cycle may be implicated in post-germinative root growth reduction caused by cadmium, by methyl viologen (MV) and byhydrogen peroxide (H2O2) in wheat seedlings. Although cadmium is considered a redox inactive metal, reactive oxygen species were detected in the apex root of metal-treated seedlings. Oxidative stress hastened cells displacement from the cell division zone to elongation/differentiation zone, resulting in a shortened meristem. The number of cells in the proliferation zone was lower after MV, H2O2 and 10 μM Cd2+ treatments compared to control. All treatments increased protein carbonylation. Although no modification in total Ub-conjugated proteins was detected, oxidative treatments reduced cyclin D and CDKA protein ubiquitination, concomitantly with a decrease in expression of cyclin D/CDKA/Rb/E2F-regulated genes
Keywords	Cadmium; Cell cycle; Oxidative stress; Triticum aestivum; Root growth inhibition

Title	**Polynuclear aromatic hydrocarbons (PAHs) mediate cadmium toxicity to an emergent wetland species**
Author Name	Zhenhua Zhang, Zed Rengel, Kathy Meney, Ljiljana Pantelic, Radmila Tomanovic
Journal Name	Journal of Hazardous Materials
Year	2011
Volume & Issue	189, 1 -2
Pages	119 - 126
Abstracts	Growth and pollutant removal by emergent wetland plants may be influenced by interactions among mixed pollutants in constructed wetlands. A glasshouse experiment was conducted to investigate interactive effects of cadmium (Cd) × polynuclear aromatic hydrocarbons (PAHs) × plant treatments on growth of Juncus subsecundus, Cd and PAH removal from soil and the total number of microorganisms in soil. Growth and biomass of J. subsecundus were significantly influenced by interaction of Cd and PAHs, significantly decreasing with either Cd or PAH additions, but with the effect of Cd on plant growth being stronger than that of PAHs. The mixture of low Cd and low PAH lessened Cd toxicity to plants, resulting in improved plant growth and increased Cd accumulation in plant tissues, thus enhancing Cd removal by plants. The dissipation of PAHs in soils was significantly influenced by interactions of Cd, PAH and plant presence or absence. The total number of microorganisms in soils was significantly increased by the PAH additions. The interactive effect of Cd and PAHs on plant growth may be linked to the changes in the abundance of microorganisms in the rhizosphere, probably via a positive effect of PAH metabolites and/or phytohormones produced by microorganisms on plant growth.
Keywords	Co-contamination, Constructed wetland, Juncus subsecundus, Metal, Organic pollutant, Polynuclear aromatic hydrocarbons

Title	**Interactions of zinc and cadmium toxicity in their effects on growth and in antioxidative systems in tomato plants (Solarium lycopersicum)**
Author Name	Jaouhra Cherif, , Chamseddine Mediouni, Wided Ben Ammar, Fatma Jemal
Journal Name	Journal of Environmental science
Year	2011
Volume & Issue	23, 5
Pages	837 - 844
Abstracts	The interaction between zinc and cadmium was investigated in tomato plants (Solarium lycopersicum). Ten-day-old seedlings were treated with 10 μmol/L CdCl2 associated to different concentrations of ZnCl2 (10, 50, 100, and 150 μmol/L). Zn supply clearly reduced Cd accumulation in leaves and simultaneously increased Zn concentration. Cd induced oxidative stress in leaves as indicated by an increase in thiobarbituric acid-reactive substances (TBARS) level and chlorophyll breakdown. Furthermore, compared with control, Cd-treated plants had significantly higher activities of Superoxide dismutase (SOD, EC 1.15.1.1), whereas, catalase (CAT, EC 1.111.1.6), ascorbate peroxidase (APX, EC 1.11.1.11), and glutathione reductase (GR, EC 1.6.4.2) activities were significantly suppressed by Cd addition. Zn supplementation, at low level, restored and enhanced the functional activity of these enzymes (SOD, CAT, APX and GR) as compared to Cd-alone-treated plants. The beneficial effect of adequate Zn level on Cd toxicity was confirmed by a significant decrease in TBARS level and restoration of chlorophyll content. However, when Zn was added at high level in combination with Cd there was an accumulation of oxidative stress, which was higher than that for Cd or excess Zn alone treatments. These results suggested that higher Zn concentrations and Cd are synergistic in their effect on plant growth parameters and oxidative stress.
Keywords	Solarium lycopersicum; cadmium; zinc; oxidative stress; antagonism; synergism