Copper

Title	**Physiological and biochemical responses of *Salix integra*Thunb. under copper stress as affected by soil flooding**
Author Name	Yini Cao, Chuanxin Ma, Guangcai Chen, Jianfeng Zhang, BaoshanXing
Journal Name	Environmental Pollution
Year	2017
Volume & Issue	225
Pages	644-653
Abstracts	To explore the joint effect of copper (Cu) and flooding on *Salix integra* Thunb. (*S. integra*), the physiological and biochemical parameters of the seedlings grown in Cu amended soil (50, 150, 450 mg kg^{-1}) with or without the flooding for 60 days were evaluated. The results suggested that the flooding significantly inhibited the root growth in terms of root length and root tips. The Cu exposures of 50 and 150 mg kg^{-1}notably enhanced the root growth as compared to the control. Majority of Cu was accumulated in *S. integra* roots, while flooding significantly reduced the Cu content, except the 150 mg kg^{-1} Cu treatment, but the iron (Fe) and manganese (Mn) content on the root surface were both markedly increased relative to non-flooded control. The malonaldehyde (MDA) and glutathione (GSH) contents in leaves showed a dose-response upon Cu exposure. Soil flooding enhanced the GSH level, which displayed 4.50–49.59% increases compared to its respective non-flooded treatment, while no difference was evident on MDA contents between the flooding and the non-flooded treatments. Both superoxide dismutase (SOD) and peroxidase (POD) activities were boosted while the catalase (CAT) was suppressed with increasing Cu exposure dose, and soil flooding reduced the POD and CAT activities. The elevated Cu level caused the evident increases of root calcium (Ca), potassium (K), and sulfur (S) concentrations and decreases of root phosphorus (P), sodium (Na), and zinc (Zn) concentrations. Soil flooding increased the concentrations of Fe, S, Na, Ca, and magnesium (Mg) in *S. integra* root. Taken together, our results suggested *S. integra*has high tolerance to the joint stress from Cu and flooding.
Keywords	Willow,Copper, Flooding,Oxidative, Stress Nutrients, Phytoremediation

Title	**Morphophysiological, ultrastructural, and nutritional changes induced by Cu toxicity in young *Erythrina fusca* plants**
Author Name	Vania L. Souza, Alex-Alan F. de Almeida, Pedro A. O. Mangabeira, Delmira da C. Silva, Raildo M. de Jesus & Raúl René Valle
Journal Name	International Journal of Phytoremediation
Year	2017
Volume & Issue	19, (7)
Pages	621–631
Abstracts	*Erythrina fusca* is an important legume used for shade cover in cacao plantations in Brazil. Cacao plantations receive large quantities of copper (Cu)-containing agrochemicals, mainly for control of diseases. Therefore, Cu toxicity was investigated in seedlings grown in hydroponics with increasing concentrations of Cu (0.005–32 mg L¡1) in a greenhouse. Ultrastructural analyses showed cell plasmolysis in the root cortical area and changes in thylakoid membranes at 8 mg Cu L¡1 and higher. There were changes in epicuticular wax deposition on the leaf surface at the 16 and 32 mg Cu L¡1 treatments. Leaf gas exchanges were highly affected 24 hours after application of treatments beginning at 8 mg Cu L¡1 and higher Cu concentrations. Chemical analyses showed that Cu content in E. fusca roots increased as Cu concentration in the nutrient solution increased, whereas the shoot did not show significant changes. It is also observed that excess Cu interfered with Zn, Fe, Mn, Mg, K, P, and Ca content in the different E. fusca organs. Investigation of Cu toxicity symptoms focusing on morphophysiological, ultrastructural, gas exchange, and nutritional changes would be useful to alleviate Cu toxicity in E. fusca under field conditions, an important agroforestry species in cacao plantation.
Keywords	Heavy metal, photosynthesis, shade cover species

Title	**Comprehensive Analysis of Rice Laccase Gene (OsLAC) family and Ectopic Expression of OsLac 10 Enhances Tolerance to copper stress in *Arabidopsis***
Author Name	Qingquan Liu, Le Luo, Xiaoxiao Wang, Zhengo Shen and Luqing Zheng
Journal Name	Int. J. Mol. Sci
Year	2017
Volume & Issue	18, (2)
Pages	1-16
Abstracts	Laccases are encoded by a multigene family and widely distributed in plant genomes where they play roles oxidizing monolignols to produce higher-order lignin involved in plant development and stress responses. We identified 30 laccase genes (*OsLACs*) from rice, which can be divided into five subfamilies, mostly expressed during early development of the endosperm, growing roots, and stems. *OsLACs* can be induced by hormones, salt, drought, and heavy metals stresses. The expression level of *OsLAC10* increased 1200-fold after treatment with 20 μM Cu for 12 h. The laccase activities of OsLAC10 were confirmed in an *Escherichia coli* expression system. Lignin accumulation increased in the roots of *Arabidopsis* over-expressing *OsLAC10* (*OsLAC10*-OX) compared to wild-type controls. After growth on 1/2 Murashige and Skoog (MS) medium containing toxic levels of Cu for seven days, roots of the *OsLAC10*-OX lines were significantly longer than those of the wild type. Compared to control plants, the Cu concentration decreased significantly in roots of the *OsLAC10*-OX line under hydroponic conditions. These results provided insights into the evolutionary expansion and functional divergence of *OsLAC* family. In addition, *OsLAC10* is likely involved in lignin biosynthesis, and reduces the uptake of Cu into roots required for *Arabidopsis* to develop tolerance to Cu.
Keywords	Rice, Laccase, OsLAC 10, Copper Tolerance, Copper uptake, *Arabidopsis*

Title	**Copper (Cu) stress affects carbon and antioxidant metabolism in *Coffea arabica* seedling**
Author Name	dos Santos, Jacqueline Oliveria, de Faria, Marico Espinosa, da Silva, Dayane Meireles, de Oliveria Silveria, Helbert Rezende, Campos, Cleide Nascimento, Alves Jose Donizeti
Journal Name	Australian Journal of Crop Science
Year	2017
Volume & Issue	11,(8)
Pages	960-967
Abstracts	Although copper is a micronutrient essential for the normal development of plants, both insufficient and supra optimal doses can disrupt the functioning of metabolism and the production of biomass. To study the biochemical and physiological impacts of deficiency and excess of copper in coffee, we treated 6-month-old seedlings of Coffea arabica L. Catua cultivar to three copper treatments: control (0.03 ppm), excess (0.12 ppm) and deficiency (0 ppm) for 60 days. The changes in levels of photosynthetic pigments, biomass allocation, carbohydrate partitioning, antioxidant system and proline levels were evaluated. Under deficiency and excess of copper coffee seedlings showed lower levels of chlorophyll, reduction on dry weight of shoot, lower sugar levels and higher content of hydrogen peroxide. We also observed increased levels of proline and enzymatic activity of the antioxidant system, providing conditions for the reduction of oxidative stress triggered by nutritional imbalance. In general, the results showed that coffee plants invest in antioxidant defense system as an alternative to maintain redox balance when exposed to deficiency or excess copper. However, it is not effective to prevent an increase in lipid peroxidation. Authors may indicate an optimum range for application of copper in coffee
Keywords	Antioxidant system, Proline, Carbohydrate

Title	The Effect of Copper on Plant Regeneration in Barley Microspore Culture
Author Name	Katarzyna Makowska, Sylwia Oleszczuk and Janusz zimny
Journal Name	Czech J. Genet. Plant Breed
Year	2017
Volume & Issue	53, (1)
Pages	17–22
Abstracts	Isolated microspore culture is an excellent system for the production of doubled haploids in many crops, including barley. In a more traditional barley anther culture method copper sulphate is known to enhance plant regeneration. Here we report that one hundred times higher concentration of copper sulphate in the isolated microspore culture of two spring barley genotypes compared to the standard content in the induction medium resulted in a 34% increase of total plant regeneration. Detailed analysis of plant regeneration showed that additional supplementation of copper sulphate increased not only the regeneration of green plants but also proportionately that of albino plants. Hence, the results from two studied genotypes do not support an assumption that the addition of copper reduces albinism in barley microspore culture. Keywords: albinism; androgenesis; doubled haploid; Hordeum vulgare; regenaration efficiency
Keywords	Albinism, Androgenesis, Doubled haploid, *Hordeum vulgare*, Regenaration efficiency

Title	**Anatomical peculiarities in wheat (*Triticum aestivum* L.) varities under copper stress**
Author Name	Saule Atabayeva1, Akmara nurmahanova , Aygul Akhmetova , Meyramkul Narmuratova , Saltanat Asrandina , Aizhan Beisenova , Ravilya Alybayeva and Tamara Lee
Journal Name	Pak. J. Bot
Year	2016
Volume & Issue	48,(4)
Pages	1399-1405
Abstracts	The effect of different concentrations (0.25 mM, 0.5 mM) of Cu2+ on anatomical parameters of leaves and roots was investigated in hydroponically grown five wheat (Triticum aestivum L.) varieties (Kazakhstanskaya rannaya, Kazakhstanskaya-3, Melturn, Kaiyr and Shagala). The results showed that wheat varieties exposed to 0.5 mM Cu2+ exhibited significant alterations in anatomical structure of leaves and roots. The thickness of the upper and lower epidermis, diameter of vascular bundles of leaves of almost all varieties showed a tendency to decrease under copper stress. Our experiments showed an activation of defense responses in the root anatomical structure like exodermis thickening in some varieties in the presence of copper in growth medium as compared to the control. This indicates that copper ions increase the thickness of exodermis, which reduce the absorption of toxic elements by root cells. Copper stress caused a decrease in the thickness of the lower and upper epidermis to varying degrees and reduction in the diameter of vascular bundles of wheat leaves. Copper stress caused a reduction in endodermis thickness thereby decreasing the diameter of the central cylinder of wheat roots. Key words: Wheat, Copper, Anatomical structure, Exodermis, Endodermis, Vascular bundles, Central cylinder
Keywords	Wheat, Copper, Anatomical structure, Exodermis, Endodermis, Vascular bundles, Central cylinder.

Title	**Effects of copper-induced stress on seed germination of Maize (*Zea Mays* L.)**
Author Name	Boroş Melania-Nicoleta, V. Micle
Journal Name	Agriculture - Science and Practice
Year	2015
Volume & Issue	95
Pages	17-23
Abstracts	The existence of heavy metals in polluted soils requires remediation technologies that can solve the problem of contamination in an environmentally friendly way. Plants used in phytoremediation projects can clean the contaminated areas and can become a solution for green approaches to this issue. One of the plants with great potential in phytoremediation is Zea mays, a very common crop plant. This experiment aimed to determine the effect of the variation in concentration of copper sulphate on the germination and growth of seeds of Zea mays. We wanted to establish which is the highest concentration of copper that seeds of Zea mays can tolerate. Seedlings growth investigation and measurements were made after 7 days. The seed germination rate was high for the low concentration and control and decreased dramatically with the increase in concentration. At high concentration the abnormal development of seeds was visible, shoots and roots growing much shorter. Keywords: copper stress, crop plant, seed germination, Zea mays
Keywords	Copper stress, Crop plant, Seed germination, Zea mays

Title	**Evaluating wild grapevine tolerance to copper toxicity**
Author Name	J. Cambrollé, J.L. García , M.E. Figueroa, M. Cantos
Journal Name	Chemosphere
Year	2015
Volume & Issue	120
Pages	171 - 178
Abstracts	We evaluate copper tolerance and accumulation in Vitis vinifera ssp. sylvestris in populations from a copper contaminated site and an uncontaminated site, and in the grapevine rootstock “41B”, investigating the effects of copper (0–23 mM) on growth, photosynthetic performance and mineral nutrient content. The highest Cu treatment induced nutrient imbalances and inhibited photosynthetic function, causing a drastic reduction in growth in the three study plants. Effective concentration was higher than 23 mM Cu in the wild grapevines and around 9 mM in the “41B” plants. The wild grapevine accessions studied controlled root Cu concentration more efficiently than is the case with the “41B” rootstock and must be considered Cu-tolerant. Wild grapevines from the Cu-contaminated site present certain physiological characteristics that make them relatively more suitable for exploitation in the genetic improvement of vines against conditions of excess Cu, compared to wild grapevine populations from uncontaminated sites
Keywords	Copper, Tolerance, Toxicity, Wild grapevine

Title	**The effect of excess copper on growth and physiology of important food crops: a review**
Author Name	Muhammad Adrees, Shafaqat Ali, Muhammad Rizwan, Muhammad Ibrahim, Farhat Abbas, Mujahid Farid, Muhammad Zia-ur-Rehman, Muhammad Kashif Irshad, Saima Aslam Bharwana
Journal Name	Environmental Science and Pollution Research
Year	2015
Volume & Issue	22
Pages	8148 – 8162
Abstracts	In recent years, copper (Cu) pollution in agricultur- al soils, due to arbitrary use of pesticides, fungicides, indus- trial effluent and wastewater irrigation, present a major con-cern for sustainable agrifood production especially in devel- oping countries. The world's major food requirement is ful- filled through agricultural food crops. The Cu-induced losses in growth and yield of food crops probably exceeds from all other causes of food safety and security threats. Here, we review the adverse effects of Cu excess on growth and yield of essential food crops. Numerous studies reported the Cu-induced growth inhibition, oxidative damage and antioxidant response in agricultural food crops such as wheat, rice, maize, sunflower and cucumber. This article also describes the toxic levels of Cu in crops that decreased plant growth and yield due to alterations in mineral nutrition, photosynthesis, enzyme ac- tivities and decrease in chlorophyll biosynthesis. The response of various crops to elevated Cu concentrations varies depend- ing upon nature of crop and cultivars used. This review couldbe helpful to understand the Cu toxicity and the mechanism of its tolerance in food crops. We recommend that Cu-tolerant crops should be grown on Cu-contaminated soils in order to ameliorate the toxic effects for sustainable farming systems and to meet the food demands of the intensively increasing population.
Keywords	Copper, Growth, Mineral nutrition, Photosynthesis, Yield

Title	**Experimental determinations of soil copper toxicity to lettuce (Lactuca sativa) growth in highly different copper spiked and aged soils**
Author Name	Karen S. Christiansen, Ole K. Borggaard, Peter E. Holm, Martina G. Vijver, Michael Z. Hauschild, Willie J. G. M. Peijnenburg
Journal Name	Environmental Science and Pollution Research
Year	2014
Volume & Issue	22
Pages	5283–5292
Abstracts	Accurate knowledge about factors and conditions determining copper (Cu) toxicity in soil is needed for predicting plant growth in various Cu-contaminated soils. Therefore, effects of Cu on growth (biomass production) of lettuce (Lactuca sativa) were tested on seven selected, very different soils spiked with Cu and aged for 2 months at 35 °C. Cu toxicity was expressed as pEC50 (Cu^{2+}), i.e., the negative logarithm of the EC50(Cu^{2+}) activity to plant growth. The determined pEC 50(Cu^{2+}) was significantly and positively cor- related with both the analytically readily available soil pH and concentration of dissolved organic carbon [DOC] which to- gether could explain 87 % of the pEC50(Cu^{2+}) variation ac-cording to the simple equation: $pEC50\ (Cu^{2+})=0.98\times pH+ 345\times[DOC]-0.27$. Other soil characteristics, including the base cation concentrations (Na^+, K^+,Ca^{2+}, Mg^{2+}), the cation exchange capacity at soil pH (ECEC), and at pH 7 (CEC7), soil organic carbon, clay content, and electric conductivity as well as the distribution coefficient (Kd) calculated as the ratio between total soil Cu and water-extractable Cu did not corre- late significantly with pEC50(Cu^{2+}). Consequently, Cu toxic- ity, expressed as the negative log of the Cu^{2+} activity, to plant growth increases at increasing pH and DOC, which needs to be considered in future management of plant growth on Cu- contaminated soils. The developed regression equation allows identification of soil types in which the phytotoxicity potential of Cu is highest.
Keywords	Cu, DOC, pH, EC50, Soilcontamination, LCA

Title	**Copper toxicity in Chinese cabbage is not influenced by plant sulphur status, but affects sulphur metabolism-related gene expression and the suggested regulatory metabolites**
Author Name	M. Shahbaz, C. E. E. Stuiver, F. S. Posthumus, S. Parmar, M. J. Hawkesford and L. J. De Kok
Journal Name	Plant biology
Year	2014
Volume & Issue	16, 1
Pages	68–78
Abstracts	The toxicity of high copper (Cu) concentrations in the root environment of Chinese cabbage (Brassica pekinensis) was little influenced by the sulphur nutritional status of the plant. However, Cu toxicity removed the correlation between sulphur metabolism-related gene expression and the suggested regulatory metabolites. At high tissue Cu levels, there was no relation between sulphur metabolite levels viz. total sulphur, sulphate and water-soluble non-protein thiols, and the expression and activity of sulphate transporters and expression of APS reductase under sulphate-sufficient or-deprived conditions, in the presence or absence of H2S. This indicated that the regulatory signal transduction pathway of sulphate transporters was overruled or by-passed upon exposure to elevated Cu concentrations.
Keywords	Abiotic stress, APS reductase, H 2 S, heavy metals, sulphate deprivation, sulphate reduction, sulphate transporters, sulphur assimilation, thiol compounds

Title	**Exogenous sodium nitroprusside and glutathione alleviate copper toxicity by reducing copper uptake and oxidative damage in rice (Oryza sativa L.) seedlings**
Author Name	Mohammad Golam Mostofa, Zeba Islam Seraj, Masayuki Fujita
Journal Name	Protoplasma
Year	2014
Volume & Issue	251
Pages	1373 – 1386
Abstracts	Nitric oxide (NO) and glutathione (GSH) regulate a variety of physiological processes and stress responses; how- ever, their involvement in mitigating Cu toxicity in plants has not been extensively studied. This study investigated the interactive effect of exogenous sodium nitroprusside (SNP) and GSH on Cu homeostasis and Cu-induced oxidative dam-age in rice seedlings. Hydroponically grown 12-day-old seed- lings were subjected to 100µ MCuSO4 alone and in combination with 200µ M SNP (an NO donor) and 200µ MGSH. Cu exposure for 48 h resulted in toxicity symptoms such asstunted growth, chlorosis, and rolling in leaves. Cu toxicity was also manifested by a sharp increase in lipoxygenase (LOX) activity, lipid peroxidation (MDA), hydrogen peroxide (H2O2), proline (Pro) content, and rapid reductions in bio-mass, chlorophyll (Chl), and relative water content (RWC). Cu-caused oxidative stress was evident by overaccumulation of reactive oxygen species (ROS; superoxide (O2•–)and H2O2). Ascorbate (AsA) content decreased while GSH and phytochelatin (PC) content increased significantly in Cu-stressed seedlings. Exogenous SNP, GSH, or SNP+GSH decreased toxicity symptoms and diminished a Cu-induced increase in LOX activity, O2•–, H2O2, MDA, and Pro content.They also counteracted a Cu-induced increase in superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR), monodehydroascorbate reductase (MDHAR), and glyoxalase I and glyoxalase II activities, which paralleled changes in ROS and MDA levels. These seedlings also showed a significant increase in catalase (CAT), glutathione peroxidase (GPX), dehydroascorbate re- ductase (DHAR), glutathione S-transferase (GST) activities, and AsA and PC content compared with the seedlings stressed with Cu alone.
Keywords	Cu toxicity, Oxidative stress, Nitric oxide, Glutathione, Antioxidant system, Cu homeostasis