Title	**Phytoremediation and Microorganisms-Assisted Phytoremediation of Mercury-Contaminated Soils: Challenges and Perspectives**
Author Name	Emanuela D. Tiodar, Cristina L. Văcar, Dorina Podar
Journal Name	International Journal of Environmental Research and Public Health
Year	2021
Volume and Issue	18(5)
Pages	2435
Abstracts	Mercury (Hg) pollution is a global threat to human and environmental health because of its toxicity, mobility and long-term persistence. Although costly engineering-based technologies can be used to treat heavily Hg-contaminated areas, they are not suitable for decontaminating agricultural or extensively-polluted soils. Emerging phyto- and bioremediation strategies for decontaminating Hg-polluted soils generally involve low investment, simple operation, and in situ application, and they are less destructive for the ecosystem. Current understanding of the uptake, translocation and sequestration of Hg in plants is reviewed to highlight new avenues for exploration in phytoremediation research, and different phytoremediation strategies (phytostabilization, phytoextraction and phytovolatilization) are discussed. Research aimed at identifying suitable plant species and associated-microorganisms for use in phytoremediation of Hg-contaminated soils is also surveyed. Investigation into the potential use of transgenic plants in Hg-phytoremediation is described. Recent research on exploiting the beneficial interactions between plants and microorganisms (bacteria and fungi) that are Hg-resistant and secrete plant growth promoting compounds is reviewed. We highlight areas where more research is required into the effective use of phytoremediation on Hg-contaminated sites, and conclude that the approaches it offers provide considerable potential for the future.
Keywords	mercury; microbe-assisted phytoremediation; heavy metals; Hg reduction; plants; Hg hyperaccumulator; phytovolatilization; metal sequestration

Title	**Suitability of Indian mustard genotypes for phytoremediation of mercury-contaminated sites**
Author Name	Mohd. Kafeel Ahmad Ansari, Altaf Ahmad, Shahid Umar, Muhammad Iqbal, Munir Hussain Zia, Azamal Husen, Gary Owens
Journal Name	South African Journal of Botany
Year	2021
Volume and Issue	142
Pages	12-18
Abstracts	Phytoremediation is an environment-friendly remediation technology, which has become widely accepted and is regarded as an easy and safe technique for removal of contaminants. Mercury (Hg) is one of the most toxic soil and water contaminants, which has not yet been widely treated via phytoremediation technology because Hg-accumulating plants were hitherto unknown. In the present study, ten genotypes (*viz.* Agrini, BTO, Kranti, Pusa Bahar, Pusa Basant, Pusa Bold, Pusa Jai Kisan, Vaibhav Vardhan and Varuna) of Indian mustard (*Brassica juncea L.*) were grown hydroponically under five different Hg concentrations (0–50 μM), and the changes in Hg uptake, plant growth and plant biomass were evaluated in order to determine the suitability of these genotypes, if any, for being used as Hg-phytoremediators. Genotype Pusa Jai Kisan was identified as the most Hg-tolerant genotype, accumulating up to 269.9 μg Hg g^{-1} dry weight (DW) in its subterranean parts and up to 61.7 μg Hg g^{-1} DW in its aerial parts. This genotype, therefore, seems to be quite suitable for use as a viable candidate for phytoremediation of Hg-contaminated sites.
Keywords	Hg-accumulation; Hydroponic study; Mustard genotypes; Plant tolerance; Seed germination

Title	**Mercury resistance and plant growth promoting traits of endophytic bacteria isolated from mercury-contaminated soil**
Author Name	Reni Ustiatik, Yulia Nuraini, Suharjono Suharjono, Paramsothy Jeyakumar, Christopher W. N. Anderson &E ko Handayanto
Journal Name	Bioremediation Journal
Year	2021
Volume and Issue	--
Pages	1-20
Abstracts	Mercury (Hg) is a toxic trace element that can cause serious environmental problems. The main source of Hg contamination to soil across Indonesia is artisanal and small-scale gold mining (ASGM) and strategies to manage or remove Hg from soil are needed. This study isolated Hg-resistant endophytic bacteria from indigenous local grasses (*Cynodon dactylon* and *Eleusine indica*) growing in Hg-contaminated soils to identify potential inoculants that could increase plant growth and mercury uptake for phytoremediation. Grass samples were collected from an ASGM location on Lombok Island. The grass samples (both, root and shoot) were surface sterilized, aseptically mashed, and serially diluted with 0.9% sodium chloride (v/v) and an aliquot of the extracted bacteria was cultured on Nutrient Agar across a range of HgCl2 concentration from 0 to 1000 mg/L. Thirteen bacterial isolates were tested for their ability to detoxify Hg, Hg bioaccumulation, indole acetic acid (IAA) production, ammonium production, and siderophore production. Five of thirteen isolates were Hg-resistant and survived on a medium containing 250 mg/L $HgCl_2$. One isolate from each of *E. indica and C. dactylon* showed complete Hg detoxification. The greatest Hg bioaccumulation was 85.04%. The highest expressed IAA and ammonium concentration was 13.17 mg/L and 2.58 mg/L respectively. Based on 16S rDNA sequence similarity, the two isolates with the greatest potential as inoculants (CD6 and EI6) were identified as Jeotgalicoccus huakuii (isolated from *C. dactylon*) and Bacillus amyloliquefaciens (isolated from *E. indica*) and could be used as inoculum for phytoremediation of Hg-contaminated soil in future studies.
Keywords	Endophytic diazotroph; growth promoting endophytic; Hg phytoremediation; Hg-resistant bacteria; indole acetic acid; siderophore

Title	**Bio-Mercury Remediation Suitability Index: A Novel Proposal That Compiles the PGPR Features of Bacterial Strains and Its Potential Use in Phytoremediation**
Author Name	Marina Robas, Pedro A. Jiménez, Daniel González, Agustín Probanza
Journal Name	International Journal of Environmental Research and Public Health
Year	2021
Volume and Issue	18(8)
Pages	4213
Abstracts	Soil pollution from heavy metals, especially mercury, is an environmental problem for human health. Biological approaches offer interesting tools, which necessarily involve the selection of organisms capable of transforming the environment via bioremediation. To evaluate the potential use of microorganisms in phytorhizoremediation, bacterial strains were isolated from rhizospheric and bulk soil under conditions of chronic natural mercury, which were identified and characterized by studying the following: (i) their plant growth promoting rhizobacteria (PGPR) activities; and (ii) their maximum bactericide concentration of mercury. Information regarding auxin production, phosphate solubilization, siderophore synthesis and 1-aminocyclopropane-1-carboxylic acid deaminase (ACCd) capacity of the isolates was compiled in order to select the strains that fit potential biotechnological use. To achieve this objective, the present work proposes the Bio-Mercury Remediation Suitability Index (BMR-SI), which reflects the integral behavior of the strains for heavy metal polluted soil bioremediation. Only those strains that rigorously fulfilled all of the established criteria were selected for further assays.
Keywords	heavy metal pollution; bioremediation; PGPR; BMR-SI

Title	**An underground strategy to increase mercury tolerance in *the salt marsh halophyte Juncus maritimus Lam.*: Lipid remodelling and Hg restriction**
Author Name	EtelvinaFigueira, Diana Matos, Paulo Cardoso, Carina Sá, Célia Fernandes, Romà Tauler, Carmen Bedia
Journal Name	Environmental and Experimental Botany
Year	2021
Volume and Issue	191
Pages	104619
Abstracts	Salt marshes are coastal ecosystems which are declining due to global warming and pollution, such as mercury (Hg) pollution. The extra- and intracellular mechanisms of tolerance to Hg in plants are identified but the involvement of the plasma membrane is poorly known. This study aims to identify the effects induced by Hg in plant membranes and to unravel their role on plants tolerance to Hg. *Juncus maritimus* was collected from a salt marsh historically contaminated with Hg. Two sites differing in Hg contamination were chosen. Hg concentration, membrane damage, antioxidant response and lipidomic analysis were performed in the different plant organs (roots, rhizome and leaves). The strategy of *J. maritimus* to tolerate environments contaminated by Hg seems to rely on restricting the entrance of Hg into the root cells, with a remodeling of root lipids contributing to the efficiency of this mechanism. The root lipids remodelling acts by protecting the cellular metabolism from Hg toxicity and thus reducing the effort of cells in counteracting Hg effects (e.g., antioxidant mechanisms). This knowledge can be used to develop strategies to preserve these important but vulnerable ecosystems, and can also be relevant for phytoremediation approaches.
Keywords	*Juncus maritimus*; Salt-marsh; Mercury; Antioxidant mechanisms; Membrane rafts; Lipids

Title	**Nodulated White Lupin Plants Growing in Contaminated Soils Accumulate Unusually High Mercury Concentrations in Their Nodules, Roots and Especially Cluster Roots**
Author Name	Miguel A. Quiñones, Susana Fajardo, Mercedes Fernández-Pascual, M. Mercedes Lucas and José J. Pueyo
Journal Name	Horticulturae
Year	2021
Volume and Issue	7(9)
Pages	302
Abstracts	Two white lupin (*Lupinus albus L.*) cultivars were tested for their capacity to accumulate mercury when grown in Hg-contaminated soils. Plants inoculated with a *Bradyrhizobium canariense* Hg-tolerant strain or non-inoculated were grown in two highly Hg-contaminated soils. All plants were nodulated and presented a large number of cluster roots. They accumulated up to 600 μg Hg g^{-1} DW in nodules, 1400 μg Hg g^{-1} DW in roots and 2550 μg Hg g^{-1} DW in cluster roots. Soil, and not cultivar or inoculation, was accountable for statistically significant differences. No Hg translocation to leaves or seeds took place. Inoculated *L. albus cv*. G1 plants were grown hydroponically under cluster root-promoting conditions in the presence of Hg. They accumulated about 500 μg Hg g^{-1} DW in nodules and roots and up to 1300 μg Hg g^{-1} DW in cluster roots. No translocation to the aerial parts occurred. Bioaccumulation factors were also extremely high, especially in soils and particularly in cluster roots. To our knowledge, Hg accumulation in cluster roots has not been reported to date. Our results suggest that inoculated white lupin might represent a powerful phytoremediation tool through rhizosequestration of Hg in contaminated soils. Potential uptake and immobilization mechanisms are discussed.
Keywords	*Lupinus albus*; lupin; *Bradyrhizobium canariense*; rhizobia; mercury; Hg; cluster roots; nodule; phytoremediation; rhizosequestration

Title	**Sulfur nanoparticles improved plant growth and reduced mercury toxicity via mitigating the oxidative stress in *Brassica napus L.***
Author Name	Haiyan Yuan, Qingquan Liu, Zhi Guo, Jiahao Fu, Yuming Sun, Chunsun Gu, Baoshan Xing, Om Parkash Dhankher
Journal Name	Journal of Cleaner Production
Year	2021
Volume and Issue	318
Pages	128589
Abstracts	Experiments were conducted to determine the effects of sulfur nanoparticles (SNPs) on alleviating mercury (Hg) toxicity and accumulation in *Brassica napus L.* in MS medium. The results demonstrated that 10 mg/L Hg severely inhibit *brassica* seedlings growth, whereas the addition of 300 mg/L SNPs alleviated Hg toxicity, and dry weight were improved by 42.4% (shoot) and 37.8% (root) compared to 10 mg/L Hg treatment alone. SNPs application decreased Hg accumulation in roots and shoots by 6–10 folds. Comparatively, the effect of corresponding bulk sulfur particles (BSPs) and sulfate as ionic compound for counteracting Hg toxicity and accumulation was less pronounced than SNPs treatment. Co-exposure of SNPs along with Hg also alleviated the Hg-induced oxidative stress as the MDA and H_2O_2 contents, antioxidant enzymes activities (SOD, POD, APX and GST) and glutathione (GSH) content in roots and shoots were decreased relative to Hg treatment alone. The macro (K, Ca, P, Mg) and micronutrients (Zn, Mn, Fe) concentrations in roots and shoots were elevated considerably by SNPs co-exposure compared to plants exposed to Hg only. Further, the expression of selected genes encoding the antioxidant enzymes and nutrient transporters also showed changes similar to the physiological and biochemical parameters. Our results showed that SNPs play a significant role in the decreasing Hg accumulation, counteracting the Hg toxicity, and enhancing plant biomass and nutrients accumulation in *B. napus*. These findings will be helpful in developing strategies to decrease heavy metals contamination in the food chain as well as for phytoremediation applications.
Keywords	Sulfur nanoparticles; Mercury; *Brassica napus*; Growth; Oxidative stress

Title	**Describing the toxicity and sources and the remediation technologies for mercury-contaminated soil**
Author Name	Dongye Teng Kang Mao, Waqar Ali, Guomin Xu, Guopei Huang, Nabeel Khan Niazi, Xinbin Feng and Hua Zhang
Journal Name	RSC Advances
Year	2020
Volume and Issue	10(39)
Pages	23221-23232
Abstracts	Mercury (Hg) is a natural element and its compounds are found as inorganic and organic forms in the environment. The different Hg forms (e.g., *methylmercury* (MeHg)), are responsible for many adverse health effects, such as neurological and cardiovascular effects. The main source of Hg is from natural release. Nevertheless, with the development of industrialization and urbanization, Hg-contaminated soil mainly influenced by human activities (especially near mercury mining areas) has become a problem. Therefore, much more attention has been paid to the development and selection of various treatment methods to remediate Hg-contaminated soils. This paper presented a systematical review of the recent developments for the remediation of Hg-contaminated soils. Firstly, we briefly introduced the Hg chemistry, toxicity and the main human activity-related sources of mercury in soil. Then the advances in remediation technologies for removing Hg pollution from the soil were summarized. Usually, the remediation technology includes physical, chemical and biological remediation technology. Depending on this, we further classified these remediation technologies into six techniques, including thermal desorption, electrokinetic extraction, soil washing, chemical stabilization, phytoremediation and microbial technology. Finally, we also discussed the challenges and future perspectives of remediating Hg-contaminated soils.
Keywords	cardiovascular effects; phytoremediation; Mercury; toxicity

Title	**Transgenic merA and merB expression reduces mercury contamination in vegetables and grains grown in mercury-contaminated soil**
Author Name	Rui Li, Han Wu, Jing Ding, Nan Li, Weimin Fu, Lijun Gan & Yi Li
Journal Name	Plant Cell Reports
Year	2020
Volume and Issue	39
Pages	1369–1380
Abstracts	Mercury contamination in plant food products can cause serious health risks to consumers. Transgenic approaches to enhance mercury phytoremediation have been accomplished with expression of bacterial *merA* and *merB* genes to convert toxic organic mercury to less toxic elemental mercury. However, little is known whether these genes can be used to produce safe foods from plants grown on mercury-contaminated land. We have used Arabidopsis and tobacco as model plants for leafy vegetables, and tomato and rice as representative fruit and grain crops to investigate whether merA and merB expression allows for production of safe foods from mercury-contaminated soils. Our results show that grown on heavily contaminated land with mercury, *merA* and *merB* expressing transgenic plants can produce vegetables, fruits and grains safe for human and animal consumption, while the wild-type plants cannot. The *merA* and *merB* transgenic plants can also efficiently remove mercury from soil. With increasing mercury contamination problems for the agricultural land worldwide, the use of the *merA* and *merB* genes can help produce safe food from mercury-polluted land and also remediate contaminated soils.
Keywords	Mercury; *MerA*; *MerB*; Vegetable; Grains

Title	**Nanoactivated Carbon Reduces Mercury Mobility and Uptake by *Oryza sativa L*: Mechanistic Investigation Using Spectroscopic and Microscopic Techniques**
Author Name	Jianxu Wang, Sabry M. Shaheen, Christopher W. N. Anderson, Ying Xing, Shirong Liu, Jicheng Xia, Xinbin Feng, Jorg Rinklebe
Journal Name	Environmental Science & Technology
Year	2020
Volume and Issue	54(5)
Pages	2698-2706
Abstracts	Mercury (Hg) contamination of paddy field poses a health risk to rice consumers, and its remediation is a subject of global scientific attention. In recent years focus has been given to in situ techniques which reduce the risk of Hg entering the food chain. Here, we investigate the use of nanoactivated carbon (NAC) as a soil amendment to minimize Hg uptake by rice plants. Application of 1-3% NAC to soil (by weight) reduced Hg concentration in the pore water (by 61-76%) and its bioaccumulation in the tissues of rice plants (by 15-63%), relative to the corresponding control. Specifically, NAC reduced the Hg concentration of polished rice by 47-63% compared to the control, to a level that was 29-49% lower than the food safety value (20 ng g^{-1}) defined by the Chinese government. The NAC induced a change in Hg binding from organic matter to nano-HgS in the soil as a function of soil amendment. This Hg speciation transformation might be coupled to the reduction of sulfoxide to reduced sulfur species (S^0) by NAC. The NAC amendment may be a practical and effective solution to mitigate the risk of Hg transferring from contaminated soil to rice grains at locations around the world.
Keywords	nanoactivated carbon; food chain; Mercury; transformation

Title	**Effects of mercury binding by humic acid and humic acid resistance on mercury stress in rice plants under high Hg/humic acid concentration ratios**
Author Name	Yue Liu, Liangliang Zhi, Shaoqi Zhou & Feng Xie
Journal Name	Environmental Science and Pollution Research
Year	2020
Volume and Issue	27
Pages	18650–18660
Abstracts	Due to the nonsystematic nature of previous studies on mercury (Hg) mobility with humic substances (HS) in terrestrial ecosystems and the uncertainty of Hg accumulation in plants, oxygen-rich humic acid (HA), which is the main component of HS, was used as the target in this study. Batch sorption tests and a series of pot experiments were designed to investigate the effect of HS on Hg binding and therefore Hg uptake in rice plants under extreme conditions, i.e., a high Hg/HS concentration ratio. The results showed that HA was eligible for Hg binding, though it has a tiny proportion of sulfur according to its characteristics analysis. The binding of HA and Hg was a chemisorption process in a single layer that followed the pseudo-second order and Langmuir models, and it was also verified that the pH was dependent on the ion strength associated with high Hg/HA concentration ratios. Based on the pot experiments, the performance of HA with Hg was investigated. The Hg in the toxicity characteristic leaching procedure (TCLP) leachate under high Hg/HA concentration ratios declined significantly, and accordingly, all treatments met the concentration criteria of 0.1 mg/l (GB 5085.3–2007) for wastes after 30 days of exposure. At concentration ratios of 50, 25, and 10 μg Hg/mg HA, we observed that HA application promoted rice plant growth, as reflected in the increase of fresh weight of different organs. Regarding accumulation in the soil-plant system, the degradation of HA to smaller molecules by rhizosphere microorganisms and organic acids in roots made HA available for plant uptake through the vascular bundle in roots, thus promoting Hg transformation in plants to a certain extent. However, considering the decline in available Hg in the soil, the Hg concentrations of roots, straw, and grains in the ripening stage were found to be lower than those in the standalone Hg treatments. HA clearly has a direct effect on Hg and an indirect influence on plants exposed to Hg under extreme conditions (very high Hg/HA concentration ratios); thus, the biogeochemical behavior of Hg at high Hg/HA concentration ratios should be considered and further investigated.
Keywords	Mercury; Humic acid; Sorption; Binding; Soil; Rice plants

Title	**Bioaccumulation of Hg in Rice Leaf Facilitates Selenium Bioaccumulation in Rice (*Oryza sativa L.*) Leaf in the Wanshan Mercury Mine**
Author Name	Chuanyu Chang, Chongying Chen, Runsheng Yin, Yuan Shen, Kang Mao, Zhugen Yang, Xinbin Feng, and Hua Zhang
Journal Name	Environmental Science & Technology
Year	2020
Volume and Issue	54 (6)
Pages	3228-3236
Abstracts	Mercury (Hg) bioaccumulation in rice poses a health issue for rice consumers. In rice paddies, selenium (Se) can decrease the bioavailability of Hg through forming the less bioavailable Hg selenides (HgSe) in soil. Rice leaves can directly uptake a substantial amount of elemental Hg from the atmosphere, however, whether the bioaccumulation of Hg in rice leaves can affect the bioaccumulation of Se in rice plants is not known. Here, we conducted field and controlled studies to investigate the bioaccumulation of Hg and Se in the rice-soil system. In the field study, we observed a significantly positive correlation between Hg concentrations and BAFs of Se in rice leaves ($r^2 = 0.60$, $p < 0.01$) collected from the Wanshan Mercury Mine, SW China, suggesting that the bioaccumulation of atmospheric Hg in rice leaves can facilitate the uptake of soil Se, perhaps through the formation of Hg-Se complex in rice leaves. This conclusion was supported by the controlled study, which observed significantly higher concentrations and BAFs of Se in rice leaf at a high atmospheric Hg site at WMM, compared to a low atmospheric Hg site in Guiyang, SW China.
Keywords	Bioaccumulation; Atmosphere; Controlled study; Mercury

Title	**Critical mercury concentration in tropical soils: Impact on plants and soil biological attributes**
Author Name	F R D Lima, G C Martins, A O Silva, I C F Vasques, M M Engelhardt, G S Cândido, P Pereira, R H C L Reis, G S Carvalho, C C Windmöller, F M S Moreira, L R G Guilherme, J J Marques
Journal Name	The Science of the Total Environment
Year	2019
Volume and Issue	666
Pages	472-479
Abstracts	Mercury is a toxic element that becomes a problem when present at high concentrations in soils. Mercury toxicity in soils varies depending on chemical species, concentration, exposure routes, and organism vulnerability. There is little information regarding the toxicity of Hg in tropical soils, especially for establishing safe levels of this pollutant. The purpose of this study was to investigate Hg concentrations in two tropical soils and their effect on oats and common beans, as well as on soil biological attributes. The experiment was carried out in a greenhouse, following ISO 11.269-2 and OECD-208 guidelines. Oat and common bean were cultivated in a *Typic Hapludox* (TyHpx) and *Rhodic Acrudox* (RhAcx) contaminated with $HgCl_2$ at the following concentrations: 0, 2.5, 5.0, 10.0, 20.0, 40.0, and 80.0 mg of Hg kg^{-1} of dry soil. The biological variables analyzed were seedling emergence, vegetative growth, chlorophyll content (SPAD index), gas exchange (photosynthetic rate, internal CO_2 concentration, transpiration rate, and stomatal conductance), and Hg concentration and accumulation in shoot dry matter. Microbial biomass carbon, soil basal respiration, and metabolic quotient (qCO_2) were also analyzed. Due to the sorptive characteristics of TyHpx, it had higher Hg concentrations than RhAcx. Mercury showed toxic effects on both oat and common bean species. However, common bean was affected only at concentrations higher than 20 mg kg^{-1}. The microbial community showed high sensitivity to soil Hg concentrations, but external factors, such as the plant species cultivated, influenced the sensitivity of the community. The microbiota was most sensitive in pots with common bean, and this effect was more pronounced at low clay and low organic matter contents (TyHpx). In this study, the concentration of 0.36 mg kg^{-1} was critical for Hg in these soils, based on its deleterious effects on oat and common bean and on biological soil attributes.
Keywords	Avena sativa; Phaseolus vulgaris; phytotoxicity; trace elements.

Title	**Mercury mobility and effects in the salt-marsh plant Halimione portulacoides: Uptake, transport, and toxicity and tolerance mechanisms**
Author Name	Maria Teresa Cabrita, Bernardo Duarte, Rute Cesário, Ricardo Mendes, Holger Hintelmann, Kevin Eckey, Brian Dimock, Isabel Caçador & João Canário
Journal Name	The Science of the Total Environment
Year	2019
Volume and Issue	650
Pages	111-120
Abstracts	The plant *Halimione portulacoides*, an abundant species widely distributed in temperate salt-marshes, has been previously assessed as bioindicator and biomonitor of mercury contamination in these ecosystems. The present study aims to assess uptake and distribution of total mercury (THg) and methylmercury(MMHg) within *H. portulacoides*, potential mercury release by volatilization through leaves, and toxicity and tolerance mechanisms by investigating plant photochemical responses. Stem cuttings of *H. portulacoides* were collected from a salt-marsh within the Tagus estuary natural protected area, and grown under hydroponic conditions. After root development, plants were exposed to $^{199}HgCl_2$ and CH3201HgCl, and sampled at specific times (0, 1, 2, 4, 24, 72, 120, 168 (7 days) and 432 h (18 days)). After exposure, roots, stems and leaves were analysed for total 199Hg (T199Hg) and MM201Hg content. Photobiology parameters, namely efficiency and photoprotection capacity, were measured in leaves. Both THg and MMHg were incorporated into the plant root system, stems and leaves, with roots showing much higher levels of both isotope enriched spikes than the other plant tissues. Presence of both mercury isotopes in the stems and leaves and high significant correlations found between roots and stems, and stems and leaves, for both THg and MMHg concentrations, indicate Hg translocation between the roots and above-ground organs. Long-term uptake in stems and leaves, leading to higher Hg content, was more influenced by temperature and radiation than short-term uptake. However, the relatively low levels of both THg and MMHg in the aerial parts of the plant, which were influenced by temperature and radiation, support the possibility of mercury release by stems and leaves, probably via stomata aperture, as a way to eliminate toxic mercury. Regarding photochemical responses, few differences between control and exposed plants were observed, indicating high tolerance of this salt marsh plant to THg and MMHg.
Keywords	Mercury; Methylmercury; *Halimione portulacoides*; Accumulation; Translocation; Photochemical responses; Salt marshes

Title	**Responses of the grass *Paspalum distichum L.* to Hg stress: A proteomic study**
Author Name	WenDing, Jin Zhang, Sheng-Chun Wu, Su Zhang, Peter Christie & Peng Liang
Journal Name	Ecotoxicology and Environmental Safety
Year	2019
Volume and Issue	183
Pages	109549
Abstracts	*Paspalum distichum L.* was tested to evaluate its ability to phytoremediate mercury (Hg) contaminated soil over a 60-d period by analysis of the total Hg concentrations in roots and leaves. Hg concentration in Hg-contamination soil decreased by 70.0 μg g^{-1} after 60 day of grass cultivation and Hg was readily taken up by the roots (4.51 ± 1.90 μg g^{-1}) rather than the leaves (0.35 ± 0.02 μg g^{-1}). In addition, a comparative proteomic study was performed to unravel the protein expression involved in the Hg stress response in *P. distichum L.* A total of 49 proteins were classified as differentially proteins in the roots by the 'top three' proteomic analysis, of which 32 were up-regulated and 17 down-regulated in response to Hg stress. These changed proteins were classified by gene ontology analysis into five complex molecular functions involving photosynthesis and energy metabolism (31%), oxidative stress (14%), protein folding (16%), sulfur compound metabolism (10%), metal binding, and ion transport (29%). Moreover, the protein expression patterns were consistent with the metabolism pathway results. Overall, the results contribute to our understanding of the molecular mechanisms of the Hg response in *P. distichum* and we propose a theoretical basis for the phytoremediation of Hg-contaminated soils.
Keywords	Soil mercury; *Paspalum distichum L;* Proteomics; Phytoremediation

Title	**Mercury and other trace metals in lettuce *(Lactuca sativa)* grown with two low-salinity shrimp effluents: Accumulation and human health risk assessment**
Author Name	Jesús A. León-Cañedo, Suammy G. Alarcón-Silvas, Juan F. Fierro-Sañudo, Gustavo A. Rodríguez-Montes de Oca, Leopoldo Partida-Ruvalcaba, Tomás Díaz-Valdés & Federico Páez-Osuna
Journal Name	The Science of the Total Environment
Year	2019
Volume and Issue	650, Part 2
Pages	2535-2544
Abstracts	Shrimp farming effluents from two sources of low-salinity water, well water (WW) and diluted seawater (DSW) (salinity, 1.7 g L^{-1}; electrical conductivity, 2.7 dS m^{-1}), were used to grow lettuce (*L. sativa*) in order to assimilate the nutrients present in shrimp effluents and produce edible biomass. The two treatments, WW and DSW, were tested in triplicate. Additionally, one hydroponic system in triplicate was constructed to grow lettuce using a nutritive solution as the control treatment (HS). The production variables of lettuce in the two crop varieties (Parris Island (VPI) and Tropicana M1 (VTM1)) showed a general trend of DSW > HS > WW with regards to the size, weight and total foliage, except for the number of leaves, which was higher with HS treatment than with WW and DSW treatments. The accumulation of Cu, Hg, Mn and Zn in edible lettuce tissue and the health risk by the intake of lettuce were evaluated. Heavy metal concentrations in edible lettuce tissue for the three treatments showed the same trend of Mn > Zn > Cu > Hg, with concentration ranges of 47.1 to 188.7, 35.7 to 66.2, 4.1 to 6.4, and 0.01 to 0.02 mg kg^{-1} (dry weight), respectively. Such concentrations did not exceed the safe limits (CAC, 1984). The health risk index and target hazard quotient were <1, which indicates that the population exposed to these metals due to intake from lettuce consumption is unlikely to have adverse health effects when shrimp farming effluents are used to grow lettuce plants.
Keywords	Heavy metals; Lettuce; *Lactuca sativa*; Shrimp farming; Health risk assessment; Daily intake

Title	**Mangifera indica as Bioindicator of Mercury Atmospheric Contamination in an ASGM Area in North Gorontalo Regency, Indonesia**
Author Name	Hendra Prasetia, Masayuki Sakakibara, Koji Omori, Jamie S. Laird, Koichiro Sera and Idham A. Kurniawan
Journal Name	Geosciences
Year	2018
Volume and Issue	8 (1)
Pages	31
Abstracts	We report the atmospheric Hg contamination in an artisanal and small-scale gold mining (ASGM) area in North Gorontalo, Indonesia. It is well known that atmospheric Hg contaminates the air, water, soil, and living organisms, including trees. In this study, we calculated total weight of heavy metals, especially Hg, and quantitatively measure the concentrations of heavy metals, especially Hg, in tree bark from an ASGM area. Tree bark can be used for the environmental assessment of atmospheric contamination because it attaches and absorbs heavy metals. Atmospheric Hg and other heavy metals, including Fe and Mn, and As were detected on the tree bark samples. The total weight of Hg, As, Fe, and Mn in the tree bark samples ranged from undetectable (ND) to 9.77,NDto 81.3, 124–4028, 37.0–1376 _g dry weight (DW), respectively per weight of sample. Based on quantitatively analysis micro-PIXE, the highest concentrations of all these metals were detected in the outer part of the bark. We conclude that tree bark can absorb atmospheric contamination, which is then absorbed into the inner tissues.
Keywords	atmospheric; mercury; ASGM; environmental; tree bark; heavy metals

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Keywords	atmospheric; mercury; ASGM; environmental; tree bark; heavy metals

Title	**Evaluation of leafy vegetables as bioindicators of gaseous mercury pollution in sewage-irrigated areas**
Author Name	Shun-an Zheng, Zeying Wu, Chun Chen, Junfeng Liang, Hongkun Huang, Xiangqun Zheng
Journal Name	Environmental Science and Pollution Research
Year	2018
Volume and Issue	25 (1)
Pages	413-421
Abstracts	Mercury (Hg) can evaporate and enter the plants through the stomata of plant leaves, which will cause a serious threat to local food safety and human health. For the risk assessment, this study aimed to investigate the concentration and accumulation of total gaseous mercury (TGM) in five typical leafy vegetables (Chinese chives (*Allium tuberosum Rottler*), amaranth (*Amaranthus mangostanus L.*), rape (*Brassica campestris L.)*, lettuce (*Lactuca sativa L.*), and spinach (*Spinacia oleracea L.*)) grown on sewage-irrigated areas in Tianjin, China. The following three sites were chosen to biomonitor Hg pollution: a paddy field receiving sewage irrigation (industrial and urban sewage effluents) for the last 30 years, a vegetable field receiving sewage irrigation for 15 years, and a grass field which did not receive sewage irrigation in history. Results showed that the total Hg levels in the paddy (0.65 mg kg^{-1}) and vegetation fields (0.42 mg kg^{-1}) were significantly higher than the local background level (0.073 mg kg^{-1}) and the China national soil environment quality standard for Hg in grade I (0.30 mg kg^{-1}). The TGM levels in ambient air were significantly higher in the paddy (71.3 ng m^{-3}) and vegetable fields (39.2 ng m^{-3}) relative to the control (9.4 ng m^{-3}) and previously reported levels (1.45 ng m^{-3}), indicating severe Hg pollution in the atmospheric environment of the sewage-irrigated areas. Furthermore, gaseous mercury was the dominant form of Hg uptake in the leaves or irreversibly bound to leaves. The comparison of Hg uptake levels among the five vegetables showed that the gradient of Hg accumulation followed the order spinach > red amaranth > Chinese chives > rape > lettuce. These results suggest that gaseous Hg exposure in the sewage-irrigated areas is a dominant Hg uptake route in leafy vegetables and may pose a potential threat to agricultural food safety and human health.
Keywords	Gaseous mercury; Mercury; Sewage-irrigated area; Leafy vegetable; Soil; Biological indicators

Title	**Effects of different concentrations of mercury on accumulation of mercury by five plant species**
Author Name	Zhongchuang Liu, Li-ao Wang, Jianhua Xu, Shimin Ding, Xianghua Feng, Hongyan Xiao
Journal Name	Ecological Engineering
Year	2017
Volume and Issue	106 , Part A
Pages	273-278
Abstracts	The paper studied the absorption of Hg by five common herb species selected, *Opuntia stricta*, *Aloe vera*, *Setcreasea purpurea*, *Chlorophytum comosum* and *Oxalis corniculata*, in solution with different levels of mercury. We compared the accumulation of roots and shoots of the plants selected in medium containing different concentrations of mercury. The study was to explore what extent of mercury the five plant species were suitable for absorbing and transferring. The mercury amount uptake by five herb species was tested by CVAAS. The results demonstrated that the effect of different concentrations of mercury on the accumulation condition of roots was greater than that of shoots. There was an ideal Hg concentration for transfer by each plant species. *Oxalis corniculata* was the most suitable for transferring Hg and was more suitable for repairing soils with Hg at concentrations of less than 500 μg/L.
Keywords	Phytoremediation; Mercury-contaminated soils; Accumulation

Title	**Mercury accumulation plant Cyrtomium macrophyllum and its potential for phytoremediation of mercury polluted sites**
Author Name	Yu Xun, Liu Feng, Youdan Li, Haochen Dong
Journal Name	Chemosphere
Year	2017
Volume and Issue	189
Pages	161-170
Abstracts	*Cyrtomium macrophyllum* naturally grown in 225.73 mg kg^{-1} of soil mercury in mining area was found to be a potential mercury accumulator plant with the translocation factor of 2.62 and the high mercury concentration of 36.44 mg kg^{-1} accumulated in its aerial parts. Pot experiments indicated that *Cyrtomium macrophyllum* could even grow in 500 mg kg^{-1} of soil mercury with observed inhibition on growth but no obvious toxic effects, and showed excellent mercury accumulation and translocation abilities with both translocation and bio concentration factors greater than 1 when exposed to 200 mg kg^{-1} and lower soil mercury, indicating that it could be considered as a great mercury accumulating species. Furthermore, the leaf tissue of *Cyrtomium macrophyllum* showed high resistance to mercury stress because of both the increased superoxide dismutase activity and the accumulation of glutathione and proline induced by mercury stress, which favorited mercury translocation from the roots to the aerial parts, revealing the possible reason for *Cyrtomium macrophyllum* to tolerate high concentration of soil mercury. In sum, due to its excellent mercury accumulation and translocation abilities as well as its high resistance to mercury stress, the use of *Cyrtomium macrophyllum* should be a promising approach to remediating mercury polluted soils.
Keywords	Soil; *Cyrtomium macrophyllum*; Mercury; Phytoremediation

Title	**The Ability of Water Plants to Reduce the Level of Mercury Pollution in Water Quality in Irrigation**
Author Name	Rusnam and Efrizal
Journal Name	International Journal of Waste Resources
Year	2016
Volume and Issue	6 (2)
Pages	--
Abstracts	This research was conducted on July – October 2013 about a mercury analysis which has been performed in Environmental Engineering Laboratory of Engineering Faculty, Andalas University. The level of mercury that is permitted by Government Regulation Republic Indonesia No. 82 of 2001 at the fourth grade for water are at 0.005mg/l. In that analysis, mercury contents with 0.020169 mg/l at irrigated areas in Batang Hari River. This research aims to find out the ability of water lilies (*Salvinia molesta*), wood lettuce (*Pistia stratiotes*), and water hyacinth (*Eichhornia crassipes*) to decrease the content of water level. This research used experimental methods and the initial content of heavy metals mercury (Hg) by using 0.02 mg/L, 0.06 mg/L, and 0.1 mg/L. The results at decreasing concentrations of heavy metals mercury will be compared with the quality standard of heavy metal mercury at the fourth grade of water. The result showed that water lilies (*Salvinia molesta*), wood lettuce (*Pistia stratiotes*), and water hyacinth (*Eichhornia crassipes*) were able to fix the water quality for irrigation which contaminated heavy metal (Hg). Then, mercury concentration reached a quality standard for irrigation at early concentration 0.02 mg/L during the 15 days and at early concentration 0.1 mg/L during 35 days. From the analysis, it was found that Water hyacinth (*Eichhornia crassipes*) is the best plant to decrease the concentration of heavy metals mercury.
Keywords	Water lilies (*Salvinia molesta*); Wood lettuce (*Pistia stratiotes*); Water hyacinth (*Eichhornia crassipes*); Mercury (Hg); Water quality; Phytoremediation

Title	**Mercury toxicity, molecular response and tolerance in higher plants**
Author Name	Jian Chen , Zhi Min Yang
Journal Name	Springer Science+Business Media
Year	2012
Volume and Issue	25
Pages	847–857
Abstracts	Mercury (Hg) contamination in soils has become a great concern as a result of its natural release and anthropogenic activities. This review presents broad aspects of our recent understanding of mercury contamination and toxicology in plants including source of Hg contamination, toxicology, tolerant regulation in plants, and minimization strategy. We first introduced the sources of mercury contamination in soils. Mercury exists in different forms, but ionic mercury (Hg^{2+}) is the predominant form in soils and readily absorbed by plants. The second issue to be discussed is the uptake, transport, and localization of Hg^{2+} in plants. Mercury accumulated in plants evokes severe phytotoxicity and impairs numerous metabolic processes including nutrient uptake, water status, and photosynthesis. The mechanisms of mercury-induced toxicology, molecular response and gene networks for regulating plant tolerance will be reviewed. In the case of Hg recent much progress has been made in profiling of transcriptome and more importantly, uncovering a group of small RNAs that potentially mediates plant tolerance to Hg. Several newly discovered signaling molecules such as nitric oxide and carbon monoxide have now been described as regulators of plant tolerance to Hg. A recently emerged strategy, namely selection and breeding of plant cultivars to minimize Hg (or other metals) accumulation will be discussed in the last part of the review.
Keywords	Mercury Plants; Toxicology; Tolerance; Small RNA; Gene expression; Molecular response

Title	**Expression of a Brassica napus heme oxygenase confers plant tolerance to mercury toxicity**
Author Name	QI Shen, Ming Jiang, Hua li, Li ling Che and Zhi Min Yang
Journal Name	Plant, Cell and Environment
Year	2011
Volume and Issue	34 (5)
Pages	752 – 763
Abstracts	Plant heme oxygenases (HOs) regulate biosynthesis of phytochrome which accounts for photo-acceptance and -morphogenesis. Recent studies have demonstrated that plant HOs also regulate many other physiological processes including response to environmental stimuli. To elucidate the mechanism by which HOs regulate plant adaptation to heavy metal exposure, three novel HOs genes were isolated from rapeseed (*Brassica napus*) and their expression patterns were analysed. Alignment of deduced protein sequences revealed that the three BnHOs share high identity with their corresponding orthologos (AtHO1-3) from Arabidopsis. To investigate whether the *BnHO* regulates plant tolerance to Hg toxicity, we constructed B. napus transgenic plants overexpressing BnHO-1. Under Hg stress, the transgenic plants had 1.41–1.59 folds higher biomass than the untransformants. However, overexpression of BnHO-1 resulted in less accumulation of Hg in some lines of transformants than in untransformants. The transgenic plants show lower abundance of reactive oxygen species and attenuated oxidative injury compared with the untransgenic plants. We cloned the promoter sequences of BnHO-1 from B. napus. Analysis revealed that the 1119 bp fragment contains a conserved Cd responsive element (CdRE) and others responding to multiple environmental stimuli. Transient expression in tobacco leaves showed differential responses to heavy metals (Zn, Cu, Pb, Hg and Cd).
Keywords	Heavy Metals; oxidative stress; promoter; rapeseed

Title	**Metallothionein expression in chloroplasts enhances mercury accumulation and phytoremediation capability**
Author Name	Oscar N. Ruiz, Derry Alvarez, Cesar Torres, Laura Roman and Henry
Journal Name	Daniell Plant Biotechnology journal
Year	2011
Volume and Issue	9 (5)
Pages	609–617
Abstracts	Genetic engineering to enhance mercury phytoremediation has been accomplished by expression of the *merAB* genes that protects the cell by converting Hg[II] into Hg[0] which volatilizes from the cell. A drawback of this approach is that toxic Hg is released back into the environment. A better phytoremediation strategy would be to accumulate mercury inside plants for subsequent retrieval. We report here the development of a transplastomic approach to express the mouse metallothionein gene (mt1) and accumulate mercury in high concentrations within plant cells. Real-time PCR analysis showed that up to 1284 copies of the mt1 gene were found per cell when compared with 1326 copies of the 16S rrn gene, thereby attaining homoplasmy. Past studies in chloroplast transformation used qualitative Southern blots to evaluate indirectly transgene copy number, whereas we used real-time PCR for the first time to establish homoplasmy and estimate transgene copy number and transcript levels. The mt1 transcript levels were very high with 183 000 copies per ng of RNA or 41% the abundance of the 16S rrn transcripts. The transplastomic lines were resistant up to 20 μm mercury and maintained high chlorophyll content and biomass. Although the transgenic plants accumulated high concentrations of mercury in all tissues, leaves accumulated up to 106 ng, indicating active phytoremediation and translocation of mercury. Such accumulation of mercury in plant tissues facilitates proper disposal or recycling. This study reports, for the first time, the use of metallothioniens in plants for mercury phytoremediation. Chloroplast genetic engineering approach is useful to express metal-scavenging proteins for phytoremediation.
Keywords	plastid genome; real-time PCR; bioremediation; genetic engineering; chelator; environmental biotechnology

Title	**Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants**
Author Name	S.K. Yadav
Journal Name	South African Journal of Botany
Year	2010
Volume and Issue	76 (2)
Pages	167–179
Abstracts	Plants experience oxidative stress upon exposure to heavy metals that leads to cellular damage. In addition, plants accumulate metal ions that disturb cellular ionic homeostasis. To minimize the detrimental effects of heavy metal exposure and their accumulation, plants have evolved detoxification mechanisms. Such mechanisms are mainly based on chelation and subcellular compartmentalization. Chelation of heavy metals is a ubiquitous detoxification strategy described in wide variety of plants. A principal class of heavy metal chelator known in plants is phytochelatins (PCs), a family of Cys-rich peptides. PCs are synthesized non-translationally from reduced glutathione (GSH) in a transpeptidation reaction catalyzed by the enzyme phytochelatin synthase (PCS). Therefore, availability of glutathione is very essential for PCs synthesis in plants at least during their exposure to heavy metals. Here, I reviewed on effect of heavy metals exposure to plants and role of GSH and PCs in heavy metal stress tolerance. Further, genetic manipulations of GSH and PCs levels that help plants to ameliorate toxic effects of heavy metals have been presented.
Keywords	Glutathione; Heavy metal stress; Phytochelatins; Plants; Tolerance mechanism

Title	**Growth and antioxidant responses in Jatropha curcas seedling exposed to mercury toxicity**
Author Name	Shun Gao, Chao Ou-yang, Lin Tang, Jin-qiu Zhu, Ying Xu, Sheng-hua Wang, Fang Chen
Journal Name	Journal of Hazardous Materials
Year	2010
Volume and Issue	182 (1-3)
Pages	591–597
Abstracts	Jatropha curcas seedlings were exposed to varying concentrations of mercury in order to investigate mercury accumulation, and the changes in growth and antioxidant enzyme activities using in vitro embryo germination and culture. Our results showed that mercury is readily accumulated by germinating embryos and growing seedlings, and its content was greater in the radicles than those of in the cotyledons and hypocotyls. This accumulation was directly correlated with an increase in tested mercury concentrations in the medium. Biomass in the cotyledons, hypocotyls and radicles increased gradually with increasing mercury concentrations, peaking in seedlings exposed to mercury concentration of 50 μM, and then decreased. Superoxide dismutase activities in the cotyledons, hypocotyls and radicles showed largest increment at mercury concentration of 100 μM. Peroxidase activities in the cotyledons and hypocotyls reached peaks at mercury concentration of 200 μM, and the highest activity in the radicles was observed at 100 μM. Catalase activities in the cotyledons and hypocotyls were significantly induced, and the highest activity in the radicles was observed at mercury concentration of 200 μM. Phenylalanine ammonia-lyase activities in the hypocotyls had a positive correlation to mercury concentrations, and the highest activities in the cotyledons and radicles were found at mercury concentrations of 200 and 100 μM, respectively. Analysis of superoxide dismutase, peroxidase and catalase isoenzymes suggested that different patterns depend on mercury concentrations and tissue types, and the staining intensities of these isoenzymes are consistent with the changes of these enzyme activities assayed in solutions.
Keywords	In vitro embryo culture; Mercury toxicity; ROS-scavenging enzymes; Defensive mechanism of plant