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Tolerant and Hyperaccumulators Autochthonous Plant Species from Mine Tailing Disposal Sites

M.A. Salas-Luévano[1]*, E. Manzanares-Acuña[2], C. Letechipía-de León[2] and H.R. Vega-Carrillo[2]

[1] Unidad Académica de Agronomía
Universidad Autónoma de Zacatecas
Apdo. Postal 336, 98000 Zacatecas, Zac. México

[2] Unidad Académica de Estudios Nucleares
Universidad Autónoma de Zacatecas
C. Ciprés 10, Fracc. La Peñuela, 98068 Zacatecas, Zac. México

Abstract : Mining activity in Zacatecas Mexico has generated huge areas affected by heavy metals contamination, especially lead. The phytoremediation is a user-friendly technology for the cleanup of contaminated environments. A crucial aspect for the practical use of this technique is the selection of adequate native plant species with high tolerance and capacity to accumulate the metals**.** The aim of this study was to identify autochthonous plant species that have potential capability for remediation of soil contaminated with lead. Seventeen different families of endemic plant species were identified in a polluted area showing large differences in the shoot's lead accumulation. The highest shoot Pb concentrations were found in *Amaranthus hybridus* (2208 µg/g). However, the lead bioconcentration factor for this plant is less than 1. Only for *Buddleja scordioides* (Buddlejaceae) and *Cerdia congestiflora* (Caryophilaceae) the Pb bioconcentration factors are 1.31 and 1.05, respectively, which classifies them as lead-tolerant species.

Key words : Phytoremediation, Lead, Zacatecas, Mine tailings.

Introduction

After the discovery of the American continent the exploitation of mines reached a primitive industrial scale, with the consequent production of mine or mill tailings affecting adversely air, soil and water (Iskander et al., 1994).

Mine tailings disposal sites from inactive or abandoned mine sites are worldwide prevalent in arid and semiarid regions. Major areas include northern Mexico, western United States, pacific coast of South America, southwestern Spain, western India, South Africa and Australia (Mendez and Maier, 2008).

Tailings have elevated concentrations of metals such as arsenic, cadmium, copper, manganese, iron and zinc. Is well known that, lead soil pollution causes a wide range of health and environmental problems (Kabata-Pendias and Pendias 1992).

Deposition of metal-rich wastes in terrestrial environments by the metal mining industry has generated new habitats for potential microevolution and colonization of metal adapted variants of common species and for metallophytes colonization (Baker, 1984; Bush and Barret, 1993; Ginocchio *et al*., 2002).

Abandoned and naturally recolonized old mine sites can therefore be seen not only as a liability but also a resource base of unique genetic materials of plant species suitable for phytostabilization and phytoremediation. The

* **Corresponding author :** Miguel A. Salas-Luévano; E-mail: *masalas@uaz.edu.mx*, Phone/Fax: +(52)-492 9244147

study of these plants and their colonization behavior and evolution observable on former mine sites has improved closure and rehabilitation strategies in some mined areas of developed countries (Gunn, 1995).

Interest in phytoremediation has grown significantly following the identification of metal hyperaccumulator plant species. Nowadays, approximately 400 plant species from at least 45 plant families have been reported to hyperaccumulate metals (Baker *et al.*, 1999; Reves and Baker, 2000).

The primary motivation behind the development of phytoremediative technologies is the potential for low-cost remediation (Ensley, 2000)**.** Comparing this technology to available physical and chemical methods of soil remediation, the use of plants is less disruptive to the environment (Cunningham and Berti, 2000).

The plant species hyperaccumulators may accumulate up to 100 times more metals than the regular plants (Cunningham and Ow, 1996; Vassil *et al.*, 1998) whose shoots contain concentrations larger than 100 mg Cd kg^{-1}, 1000 mg Ni, Pb and Cu kg^{-1}, or 10 000 mg Zn and Mn kg^{-1} (dry wt.) (Baker and Brooks, 1989; Baker et al., 1994). This higher plant species have adaptations that enable them to survive and to reproduce in soils heavily contaminated (Baker, 1987).

Latin America, and particularly Mexico, is rich in ore deposits; few metal-tolerant and metal-hyperaccumulator plants have been reported in this area as compared to other areas of the world (Ginocchio and Baker, 2004).

In Mexico, Olguin (2001) has utilized the aquatic floating plant *Salvinia minima* to remove lead and cadmium. In semi-arid zones in Mexico. Flores-Tavizon *et al.* (2003) have identified the *Eleocharis sp*. (Cyperaceae) as arsenic-tolerant with potential use in phytoextraction. To utilize the phytoremediation it is necessary to identify and characterize the local plant species that have developed resistance and behave as hyperaccumulators of toxic metals.

Zacatecas is located in central north of Mexico having 450 years of mining tradition with the consequent accumulation of mining tailings. In Zacatecas the metallic ores are abundant and diverse; its exploitation has been made since XVI century. The contaminated sites may offer greater potential to study the autochthonous plant species locally adapted, that can be utilized for phytoremediation of metal contaminated soils. The aim of this study was to identify the species of autochthonous plants tolerant and hyperaccumulators of metals that grows in a mining area in Zacatecas, Mexico.

Materials and Methods

Study Site

Soil and plant species samples were collected from "Francisco I. Madero" located at 22º 48' 42" latitude north and 102º 42' 058" longitude west at 2250 meters above sea level. This area is heavily contaminated with mining tailings. This site is characterized by a climate arid sub tropic tempered, throughout the year; the average temperature is 19 ^{o}C, with an annual precipitation that varies from 200 mm to 300 mm. Soils are poor in nutrients, showing a sandy texture with low moisture retention.

Sampling

Sampling was carried out from September to October 2004 during flowering period as well as in February 2005 during the dry period. Sampling area is approximately 500×500 m^2. The sampling sites were selected from old terrace alluvial with mine tailings of variable thickness and with apparently different degrees of contamination according to vegetation type, cover, and soil color. At each selected site, soil sample, to different stratums (10, 20, 30, and 50 cm-depth), and mature perennials plants as well as annual species samples, were randomly but simultaneously taken to investigate contents of lead.

Identification and Taxonomic Characterization of Plants

The selected plants were collected by triplicate. The identification and taxonomic characterization were performed at the herbarium facility of the Unidad Academica de Agronomia de la Universidad Autonoma de Zacatecas, through botanical keys (Calderon and Rzedowski, 2001), where the vouchers were deposited.

Determination of Lead Concentration

Plant Samples Preparation

The collected plants were washed four times, three times with distilled water and once with tri-distilled water. Plants were dried, and their different parts were carefully separated (root and shoot). Drying process were carried out at 60 °C for 75 h, then samples were crushed, sieved (< 325 µm), homogenized, and weighed. Later, lead was determined by Energy Dispersive X-ray Fluorescence.

Soil Samples Preparation

Soil samples were dried at 60 °C for 75 h; then each sample was crushed, sieved (< 325 µm), homogenized, and weighed**.** The characteristics of every soil stratum were obtained using conventional chemical methods. Total lead in soil and plant samples was measured by energy-dispersive x-ray fluorescence spectrometry, using a MiniPal PW4025 model from Philips Analytical. X-ray spectra were analyzed with MiniPal II software. The spectrometer was calibrated for Pb using certified standards from NIST (National Institute of Standards and Technology) Montana soil 2710 and NBS (National Bureau of Standards) 1570, 1573, and 1575. Intermediate and high lead concentration standards, traceable to NIST, were prepared in our facility to have a wide range calibration curve. The lead concentration in the samples was measured five times.

Results and Discussion

Taxonomic Identification

Based on field observations, the high concentration of lead in the natural vegetation and the soil of the studied area, seventeen different families of endemic plant species were identified which are shown in Table 1.

These are developed under conditions of acidic soil, low content of organic matter and sandy texture. These species are adapted to specific edaphic and climatic conditions of this contaminated area. This implies that tolerant plant species are able to survive to reproduce in these soils; these results agrees with Baker (1987).

Total Lead Concentrations in Plants

In Latin America few terrestrial plants have been reported to hyperaccumulate lead in natural habitats. Table 2 shows the Pb concentrations in shoots and the bioconcentration factor (BCF) which is the shoots-to-soil-metal concentration ratio. Total lead concentrations in collected plants rather varied which were different between the plant families taxa as well as between the various parts of the plants of the same species. The lead concentration in these plants were ranging from 63 to 2208 µg/g in *Eragrostis mexicana* and *Amaranthus hybridus*, respectively.

The lead concentration level observed in these plants and their environment is relatively small in comparison with those of the plants classified as hyperaccumulators, which require a concentration in their biomass of at least 1000 µg/g of the element in dried weight, and the

Table 1 : Taxonomic characterization of the associated plants species in mine tailing soils

Family	Scientific name	Common name
Agavaceae	*Yucca sp.*	Palma china
Amaranthaceae	*Amaranthus hybridus* L.	Quelite
Asteraceae	*Bidens odorata* CAV.	Aceitilla
	Heterosperma pinnatum CAV.	n. a.*
	Pseudognaphalium inornatum (D C.) A. ANDERB.	Gordolobo
	Tithonia tubiformis (JACQ.) CASS.	Girasol
Brassicaceae	*Brassica campestris* L.	Mostacilla
Buddlejaceae	*Buddleja scordioides* KUNTH	Escobillón
	Buddleja tomentella STANDL.	Tepozán
Caryophilaceae	*Cerdia congestiflora* HEMSL.	n. a. *
Chenoposiaceae	*Chenopodium graveolens* WILLD	Epazote de zorrillo
	Salsola tragus L.	Rodadora
Convolvulaceae	*Ipomoea longifolia* BENTH.	Alcaparra
Cucurbitaceae	*Cucurbita foetidissima* KUNTH	Calabacilla loca
	Sicyos laciniatus L.	Chayotillo
Fabaceae	*Lupinus campestris* CHAM. & SCHLTDL.	Hierba loca
Malvaceae	*Sphaeralcea angustifolia* (CAV.) G. DON	Hierba del negro
Mimosaceae	*Acacia schaffneri* (S. WATSON) F.J. HERM.	Huizache
	Prosopis laevigata (WILLD.) M.C. JOHNST.	Mesquite
	Mimosa aculeaticarpa ORTEGA	Gatuño
Nyctagiceae	*Mirabilis jalapa* L.	Maravilla
Pedaliaceae	*Proboscidea louisianica* (MILL.) THELL.	Torito
Poaceae	*Chloris virgata* SW.	Zacate mota
	Eragrostis cilianensis (ALL.) E. MOSHER	Amor seco
	Eragrostis mexicana (HORNEM.) LINK	Zacate barbechero
	Pennisetum villosum R. BR. EX FRESEN	Zacate plumoso
	Sporobolus airoides (TORR.) TORR.	Zacatón
Salicaceae	*Salix bonplandiona* KUNTH	Sauce
Solanaceae	*Physalis hederifolia* A. GRAY	Tomatillo
	Solanum eleagnifolium CAV.	Trompillo

n.a. not available*

capacity to bioconcentrate the element in their tissues with a BCF larger than 1.00. Currently, lead hyperaccumulator plants in the world are 14 taxas and 7 families (Ensley, 2000), while *Chenopodium ambrosioides*, *Pennisetum clandestinum* and *Bidens humilis* are the only metallophytes described in Latin America; they are reported as lead metal tolerant (Bech *et al*., 2001, 2002).

The high Pb concentration observed in shoots of *Amaranthus hybridus* (2208 µg/g), and the highest BCF value in *Buddleja*

Table 2 : Lead concentration of plants and they parts and soil

Family	Species	Lead concentration [µg/g]		BCF Shoot/Soil
		Shoot	Soil	
Amaranthaceae	*Amaranthus hybridus*	2208±136	2898±195	0.77
Brassicaceae	*Brassica campestris*	1095±84	2457±237	0.45
Buddlejaceae	*Buddleja scordioides*	1378±153	1048±104	1.31
Caryophilaceae	*Cerdia congestiflora*	1175±126	1119±114	1.05
Cucurbitaceae	*Cucurbita foetidissima*	357±69	1075±108	0.33
Fabaceae	*Lupinus campestris*	615±40	699±95	0.88
Mimosaceae	*Mimosa aculeaticarpa*	759±69	1528±144	0.49
	Acacia schaffneri	953±73	1052±87	0.9

scordioides (1.31) and *Cerdia congestiflora* (1.05) indicates that these are able to tolerate and accumulate Pb, being candidates to be used in Pb phytoextraction. However, *Cerdia congestiflora*, which is present all over the year, having good BCF is not suitable for phytoremediation due to its small biomass.

The BCF values of *Lupinus* c*ampestris* (0.88) and *Acacia schaffneri* (0.90) are lesser than one. In the majority of the mining sites of Zacatecas both plants grow favorably; they are very well adapted to heavily disturbed soils and are resistant to many environmental stresses. These features make these plants suitable to re-vegetation of contaminated soils helping to soils phytostabilization.

The lead is a major soil contaminant and very few metal-tolerant and hyperaccumulator species have been reported. In addition, field of *Phaseolus vulgaris* adjacent to old terrace alluvial with mining tailings, were sampling, the concentrations of lead in shoot were 258 ± 66, in soil 251 ± 26 having 1.03 as bioaccumulation factor. This plant has high biomass, is not commonly defined as accumulator plant; however, it can be considered as an alternative species to be used, assisted with agents chelates, in lead-phytoextraction of contaminated soils (Huang and Cunningham, 1996; Kos and Leštan, 2004).

Conclusions

The autochthonous plants identified in this study are endemic of the semi-arid region from Zacatecas, Mexico. From plants associated to this mine tailing site, only *Buddleja scordioides* can be classified as a lead tolerant plant and it is a good candidate to be used in phytoremediation of lead contaminated soils. The *Cerdia congestiflora* has a BCF value equal to one, with a low biomass yield making this plant not suitable for lead phytoextraction.

Acacia schaffneri, Lupinus campestris and Amaranthus hybridus are well adapted in this contaminated environment and grow abundantly; however the BCF is less than 1. This factor restricts their application in phytoremediation. Further investigations under controlled environmental conditions are required for evaluating the usefulness of these species in phytoremediation technologies.

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