



Screening of native plant species for phytoremediation potential at a Hg-contaminated mining site

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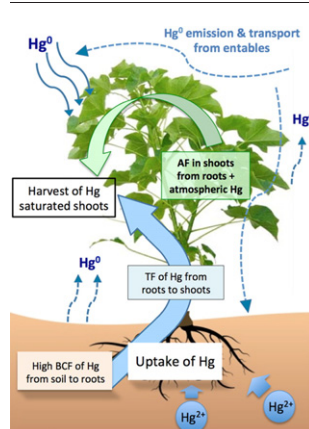
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HIGHLIGHTS

- Phytoremediation of Hg in native plants was examined at a gold mining site.
- Atmosphere Hg concentrations must be considered when assessing plant uptake.
- Thus, the Translocation Factor does not characterise plant uptake capacity.
- In gold mining sites, bioconcentration and accumulation are the best factors to use.
- Herbs and sub-shrubs are promising native plants for remediation.

GRAPHICAL ABSTRACT



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ABSTRACT

Artisanal and small-scale gold mining (ASGM) is the largest sector of demand for mercury (Hg), and therefore, one of the major sources of Hg pollution in the environment. This study was conducted in the Alacrán gold-mining site, one of the most important ASGM sites in Colombia, to identify native plant species growing in Hg-contaminated soils used for agricultural purposes, and to assess their potential as phytoremediation systems. Twenty-four native plant species were identified and analysed for total Hg (THg) in different tissues (roots, stems, and leaves) and in underlying soils. Accumulation factors (AF) in the shoots, translocation (TF) from roots to shoots, and bioconcentration (BCF) from soil-to-roots were determined. Different tissues from all plant species were classified in the order of decreasing accumulation of Hg as follows: roots > leaves > stems. THg concentrations in soil ranged from 230 to 6320 ng g⁻¹. TF values varied from 0.33 to 1.73, with high values in the lower Hg-contaminated soils. No correlation was found between soils with low concentrations of Hg and plant leaves, indicating that TF is not a very accurate indicator, since most of the Hg input to leaves at ASGM sites comes from the atmosphere. On the other hand, the BCF ranged from 0.28 to 0.99, with *Jatropha curcas* showing the highest value. Despite their low biomass production, several herbs and sub-shrubs are suitable for phytoremediation application in the field, due to their fast growth and high AF values in large and easily harvestable plant parts. Among these species, herbs such as *Piper marginatum* and *Stecherus bifidus*, and the sub-shrubs

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J. curcas and *Capsicum annuum* are promising native plants with the potential to be used in the phytoremediation of soils in tropical areas that are impacted by mining.

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1. Introduction

Mercury (Hg) is a naturally occurring element that is found in air, water, and soil, and is a toxic environmental pollutant, since it can cause severe damage to humans and wildlife (Díez, 2009). The primary means by which humans are exposed to Hg are through the consumption of contaminated food (methylmercury, MeHg, especially fish) and the inhalation of air (mainly elemental Hg, Hg⁰). These two chemical forms of Hg are of particular interest regarding artisanal small-scale gold-mining (ASGM) areas (Steckling et al., 2011). Mercury is used to extract gold from ore and is discharged in a vaporised form (Hg⁰) into the environment, where it poses a hazard to human health. Moreover, once released to environment, Hg undergoes a series of complex transformations and cycles (e.g., biotic and abiotic methylation of inorganic mercury) that produce MeHg, which fish accumulate from water (Carrasco et al., 2011).

In Colombia, the largest gold-mining area is located in northern Antioquia and southern Bolívar, and emissions to the atmosphere are ~80 to 100 t of Hg per year (Telmer and Veiga, 2008; Veiga, 2010; Cordy et al., 2011). According to data from Cordy et al., 2011, approximately 130 t of metallic Hg was imported into Colombia in 2009. The Alacrán gold mine is located in the Basin of the San Jorge River, Department of Córdoba, where Hg is used in the amalgamation process for the recovery of the precious metal (Marrugo et al., 2007) during the ASGM process. Improper handling of Hg has led to the contamination of many environmental compartments, threatening surrounding towns; a representative case is the Santa Cruz mine in the Bolívar department, where high Hg concentrations in humans have been reported (Olivero and Johnson, 2002).

Artisanal and small-scale gold mining cause alterations of the local ecosystems, and generates serious public health problems, because once released, Hg can be transported from the soil and bodies of water to humans (Islam et al., 2007). This type of mining is also considered very detrimental to the environment, due to the removal of vegetation

cover, which increases erosion. Furthermore, in many areas exploited by mining, this activity results in the emergence of a mosaic of secondary plant communities in different successional stages, according to the time and intensity of disturbance (Díaz and Elcoro, 2009). Some authors (cf. Ash et al., 1994) have indicated that the presence of plant communities at a particular site depends on the potential for seedlings to survive and reproduce. Establishment of plant species in contaminated soils indicates that they are adapted to the contaminant and as such, can remove or retain it, reducing its toxicity in soil (Chaney et al., 2000).

Plants known as hyperaccumulators can tolerate, absorb, accumulate, and translocate high levels of heavy metals (Chen et al., 2001; Thangavel and Subburam, 2004); and have been used in phytoremediation, to remove, accumulate, and inactivate these contaminants (Padmavathiamma and Li, 2007).

Our research hypothesis was that through the identification of the specific flora at the El Alacrán mine, we could identify the most useful plant species for the phytoremediation of Hg in soils used for agricultural purposes, and identify potential impacts based on the plant use (Table 1). The aim of this study was to identify autochthonous plants growing on a mining Hg-contaminated site, to assess their potential as phytoremediation systems. To this end, we determined THg content in different tissues (roots, stems and leaves), in the underlying soil samples, and Hg translocation (TF) and bioconcentration factors (BCF) in the plants. A further aim was to analyse these factors in more detail prior to making decisions concerning suitable plant selection for enhanced phytoremediation of Hg in mining areas.

2. Materials and methods

2.1. Study area

This study was conducted at the Alacrán mine (Fig. 1), located in the upper part of the basin of San Jorge River at 7°44'29.01"N to 75°44'10.8" W. First, the three-dimensional area occupied by the El Alacrán mine

Table 1
Collection of the autochthonous plant species reported in the Alacrán mine.

Family	Scientific name	Code ^a	GH	Utility
Bignoniaceae	<i>Tabebuia rosea</i> L.	4950	Tree	Wood
Cecropiaceae	<i>Cecropia peltata</i> L.	4937	Tree	Wood
Cyperaceae	<i>Cyperus ferax</i> L.	4956	Herb	Weeds
Cyperaceae	<i>Cyperus luzulae</i> Retz.	4940	Herb	Weeds
Cyperaceae	<i>Eleocharis interstincta</i> (Vahl) Roem.	4941	Aquatic herb	Ornamental, artisanal
Cyperaceae	<i>Oxycaryum cúbense</i> Poepp & Kunth.	4957	Herb	Weeds
Euphorbiaceae	<i>Jatropha curcas</i> L.	4942	Sub-shrub	Ornamental, fences of properties
Euphorbiaceae	<i>Phyllanthus niruri</i> L.	4943	Sub-shrub	Medicinal
Euphorbiaceae	<i>Ricinus communis</i> L.	4944	Sub-shrub	Ornamental, medicinal
Fabaceae	<i>Inga</i> spp.	4945	Tree	Ornamental, artisanal, food
Fabaceae	<i>Senna alata</i> L.	4946	Shrub	Degraded soils recovery
Gleicheniaceae	<i>Stecherus bifidus</i> Willd.	4947	Herb	Ornamental
Lamiaceae	<i>Plectranthus</i> spp.	4948	Herb	Medicinal, ornamental
Malvaceae	<i>Ceiba pentandra</i> L.	4952	Tree	Wood
Malvaceae	<i>Guazuma ulmifolia</i> L.	4955	Tree	Artisanal, cattle food
Marantaceae	<i>Thalia geniculata</i> L.	4938	Aquatic herb	Ornamental, artisanal
Marantaceae	<i>Calathea lutea</i> Aubl.	4958	Herb	Cultural, artisanal housing construction
Melastomataceae	<i>Clidemia</i> sp.	4949	Shrub	Ornamental
Muntingiaceae	<i>Muntingia calabura</i> L.	4951	Shrub	Ornamental, sweet fruit
Myrtaceae	<i>Psidium guajaba</i> L.	4939	Tree	Ornamental, food
Onagraceae	<i>Ludwigia octovalvis</i> L.	4960	Herb	Weeds
Piperaceae	<i>Piper marginatum</i> L.	4953	Herb	Ornamental
Pteridaceae	<i>Pytirogramma colomelanos</i> Kaulf.	4954	Herb	Ornamental
Solanaceae	<i>Capsicum annuum</i> L.	4959	Sub-shrub	Food

GH: growth habit.

^a Code of the plants deposited in the Herbarium of the University of Córdoba (HUC).

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