LEAD IN PLANTS: A BRIEF REVIEW OF ITS EFFECTS, MECHANISMS TOXICOLOGICAL AND REMEDIATION

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ABSTRACT

Environmental pollution by toxic heavy metals is one of the most serious issues that world populations have to cope with. In fact, it occurs in industrial and in agricultural regions. Lead is one of the most toxic for humans and plants with great damage for the environment. Phytotoxic activities have been registered in scientific literature by several researchers who reported its effects in many vegetal species. In fact, lead accumulation in the soil causes damage to the development of plants due to a greater concentration in the roots and distributes itself to several tissues. When absorbed by the plant can be distributed to different tissues by means of a complex network of homeostasis, causing molecular and biochemical disorders. Despite the high toxicity of lead, some plant species have been tolerant of its presence and may be used in the decontamination of soil by phytoremediation. Current research is a revision of the literature on the ecotoxicological effects of heavy metals, especially lead, and present the current technical soil remediation contaminated by the metal.
KEYWORDS: contamination, heavy metal, pollutant.

CHUMBO NAS PLANTAS: UMA BREVE REVISÃO SOBRE SEUS EFEITOS, MECANISMOS TOXICOLÓGICOS E REMEDIAÇÃO

RESUMO

A poluição ambiental por metais pesados tóxicos é um dos graves problemas enfrentados pela população mundial, estando presente nas indústrias e nas regiões agrícolas. Dentre os metais pesados, o chumbo tem sido um dos mais tóxicos para o homem e para as plantas, causando grandes preocupações ambientais. A sua ação fitotóxica tem sido reportada na literatura científica por diversos pesquisadores, que têm verificado os seus efeitos em diversas espécies de plantas. O chumbo tende a acumular no solo provocando danos ao desenvolvimento das plantas, principalmente nos tecidos radiculares. Entretanto, uma vez absorvido pelo vegetal, pode se distribuir para os diferentes tecidos por meio de uma complexa rede de homeostase, causando distúrbios bioquímico e molecular. Apesar da alta toxicidade do chumbo, algumas espécies de plantas têm apresentado tolerância a se desenvolver em sua

presença, sendo estudadas como prováveis remediadoras do solo contaminado, por meio da técnica de fitorremediação. O objetivo dessa pesquisa foi fazer uma revisão de literatura sobre os mecanismos e efeitos toxicológicos dos metais pesados, particularmente do chumbo, nas plantas, assim como apresentar técnicas atuais que buscam remediar o solo contaminado por esse metal.
PALAVRAS-CHAVE: contaminação, metal pesado, poluente.

INTRODUCTION

Human activities have increased the disposal of heavy metals in several compartments of the biosphere (KEMERICH et al., 2014). These chemical elements, namely, metals with specific weight higher than 5 g cm^{-3} (BERTOLI, 2011) or any other element associated with pollution issues (OLIVEIRA, 2008), have a fundamental role in mineral nutrition of plants. Although zinc (Zn), iron (Fe) (SILVA, 2014), copper (Cu) and cobalt (Co) (SILVA, 2007) are highly important as micronutrients, at high levels or replaced by other metals, such as lead (Pb), mercury (Hg) and cadmium (Cd), are dangerous and cause toxic effects and even death to plants (SILVA, 2014).

Heavy metals pollute the environment, with lead as potentially toxic due to its accumulative characteristics in the soil, with great damage to plant development. In fact, it is listed as the most dangerous on the list of the US Environmental Protection Agency (ATSDR, 2008).

Forest areas, soil and water have been contaminated by wastes derived from anthropic activities which may contain high amounts of heavy metals (ALMEIDA et al., 2008). In fact, pollution by heavy metals in agriculture is a great environmental concern (PEREIRA et al., 2013).

The toxicity mechanism in plants involves a complex network mobilization and ground root absorption and transport, capture and distribution in the intracellular plant space (CLEMENS et al., 2002), with effects on biochemical and molecular levels that may cause imbalance in the homeostasis of essential metals (DUBEY & SHARMA, 2005), damage to biomolecules, oxidative stress, and hence effects on plant development (HOSSAIN et al., 2011).

Plants cultivated in soils with high concentrations of lead are impaired in their growth and development (SOUZA et al., 2011). Research on the assimilation of plants by heavy metals has found that this metal can cause negative consequences related to the growth of the plant (SOUZA et al., 2011) and seed germination, and may restrict the chlorophyll productivity and cause damage to genetic material and change the operation of the plant enzyme (RIBEIRO et al., 2015).

Currently, several studies have evaluated techniques to remediate soils contaminated by lead (TANG et al., 2015), either in their own environment (*in situ*) or transporting the soil to be treated out of the environment (*ex situ*). However, *ex situ* techniques are considered more impactful to the environment. Among the techniques *in situ* phytoremediation has been much studied in the research of plant species with probable tolerance to develop in soil contaminated by this metal (OLIVEIRA et al., 2014; ALMEIDA, 2014; GOUVEIA et al., 2015).

Current research is a revision of the literature on the ecotoxicological effects of heavy metals, especially lead, and present the current technical soil remediation contaminated by the metal.

LITERATURE REVIEW

Environmental contamination by heavy metals

Environmental degradation has increased concern about the toxic effects of heavy metals (MORAES, 2011) in the soil, causing serious consequences for people's health contaminate plants (ATSDR, 2008), compromising the sustainability of agricultural production.

Heavy metals may be derived from natural sources, such as vulcanism, redistribution by wind and water (KLEIN & HOEHNE, 2015). but environmental contamination by anthropic sources became a grave issue that affects the environment (SILVA, 2014; OLIVEIRA & JUCÁ; 2014). These sources originate from several activities such as mining, industrial works, fertilizers in agriculture (ALMEIDA et al., 2008; AUGUSTO, et. al., 2014), drainage sludge and organic compounds from the recycling of urban wastes in the soil (MORAES, 2011).

Waste deposits in the soil containing metals with high toxic potential increase bio-available concentrations in the environment (SILVA, 2014) and may cause serious environmental damage (SILVA, 2006) due to high toxicity of the pollutants (BERTOLI, 2011). Soil contamination is a threat to biodiversity since soil is essential for the growth of plants and the deterioration of dead matter required for nutrient recycling (SILVA, 2006).

Industries are the main sources of pollution since they dump non-treated wastes into rivers and lakes (OLIVEIRA, 2007), in the soil and into the atmosphere (GONÇALVES, 2009). Cadmium, lead, chromium, nickel, mercury, zinc, arsenic and iron are among the main metals used in industrial development (PINO, 2005), whereas metallurgy of heavy metals causes most pollution among industrial activities. In fact, it pollutes the surrounding area and destroys vegetal life (ANDRADE et al., 2009).

Mining is another activity on which humans, for survival and profit, lack the required knowledge on its effects on the environment (POLETTI et al., 2014). It may cause the destruction of vegetation and the consequent degradation of the soil through erosion and leeching of the metal to underground water (SOUZA & REISSMANN, 2009), with concentration increase of heavy metals in the water milieus (OLIVEIRA, 2007).

Leeching and metal-contaminated landslides from mining may also contaminate underground waters while reaching other areas (PRESTON et al., 2014). Intense and inadequate use of agricultural fertilizers, which may contain heavy metals in their chemical composition, increases soil pollution (RANGEL et al., 2006) with the subsequent accumulation in soils affecting plants at phytotoxic levels, contaminate water (SILVA et al., 2007). Toxic effects by fertilizers depend on the concentration, combination and accumulative effect of the compounds in the chemical compositions (SILVA, 2006).

The possibility of soil contamination by heavy metals is related to adsorption, the passage from the liquid to the solid phase and; to desorption processes, or rather, the elements influenced by the type of clay, pH of soil, cation exchange capacity, rates of organic matter, which also affect the concentration and availability of these elements to plants (BERTOLI, 2011).

Heavy metals in the soil may react chemically and biochemically and thus affect the availability and toxicity in plants (BERTOLI, 2011). Concentration and subsequent accumulation of these elements in vegetal tissues mainly depend on their availability in the soil and their toxicity may be perceived because of several changes in the plants´ growth and development (SILVA, 2006) due to the occurrence of morphological, physiological, biochemical and structural performances (MORAES, 2011). Heavy metals of the group of metallic, semi-metallic and selenium elements are chemical pollutants that cause negative effects on the biota (CHAVES, 2013).

Lead: characteristics, sources and concentration levels in the environment

Lead is a silvery white, highly malleable, non-corrosive, potentially toxic metallic element (SILVA, 2014). It is produced from minerals such as cerrusite ($PbCO_3$), anglesite ($PbSO_4$) and galena (PbS), of which the latter is the most important source (MAZUCCO, 2008). It has a low fusion point, high density and simple industrial handling (GONÇALVES, 2009).

Lead is one of the most toxic elements known and with which humans have daily contact. The production of alloys (bronze, brass), the manufacture and recovery of batteries, glazing of ceramics, manufacture of pigments, PVC and plastics, rubbers, glasses, electrical cables, welding and electric plates are among its several uses (GRIGOLETTO, 2011). It is also used in firearms, fertilizers and pesticides, fuel additive and as refrigerating element after fusion (SILVA, 2014). Lead may thus occur in all environments due to its wide applications in several products (WEI et al., 2014).

Metal disposal may occur in the atmosphere or in soil and water (GERHARDSSON et al., 2012). Lead is a highly common element on the earth´s crust (BERTOLI, 2011) with a mean concentration of 10-20 mg kg^{-1} in soils; as a natural concentration of approximately 0.0005 µg/m^3 in the atmosphere; and approximately 0.02 µg/L in surface waters (GONÇALVES, 2009). Toxicity level of lead in plants ranges between 30 and 300 mg kg $^{-1}$ (OLIVEIRA, 2008).

It is estimated that 330,000 tons of lead are disposed of into the atmosphere every year. Approximately 20% of lead particles are dispersed into the air, In fact, air is the metal´s main dispersal mode, carried off by rain and accumulate in the soil and water (CAPELLINI et al., 2013).

Further, depending on such factors as geographic position and emission levels in the region, approximately 40-70% of lead disposal occurs in moisture precipitations at an annual rate of $0.18x10^{-6}$, which is low when compared to other metals under analysis (FERNANDES et al., 2011).

Lead levels in the soil depend on heavy car traffic and industrial activities where they are higher than in isolated sites (CAPELLINI et al., 2013). Soil is contaminated by heavy metals when the amount of metal exposed to the environment is higher than the soil´s retention capacity. In this case, it is absorbed by the plants or carried to underground water causing contamination (FERNANDES et al., 2011).

Populations worldwide have been coping with serious contamination problems of soil and air caused by lead accumulation. The issue is very serious since lead has a cumulative process with concentrations varying between the warning rate of 72 mg kg^{-1} and 180, 300 and 900 mg kg^{-1} respectively for intervention in agricultural, residential and industrial areas (MORAES, 2011).

Mean lead rates of approximately 17 mg kg^{-1} occur in Brazilian latosols (ALCÂNTARA et al., 2011). Moreover, heavy metals accumulate in the soil, mainly at

0-20 cm surface layer, where they come in contact with plant roots (BERTOLI, 2011). WHO suggests 10 µg L^{-1} (48.3 nmol L^{-1}) as the tolerated limit for lead in water, also adopted by Brazil in Resolution 2914/2011 of Ministry of Health (GRIGOLETTO et al., 2012).

Toxicity mechanism and toxicological of lead in plants

Knowledge on the homeostasis network of metals in living beings is a recent matter (CLEMENS, 2001). The accumulation of metals in plants involves a very complex process. According to Clemens et al. (2002, p. 311), the molecular mechanism for the transition of metals from the soil to the plants´ tissues follows the steps below (Figure 1):

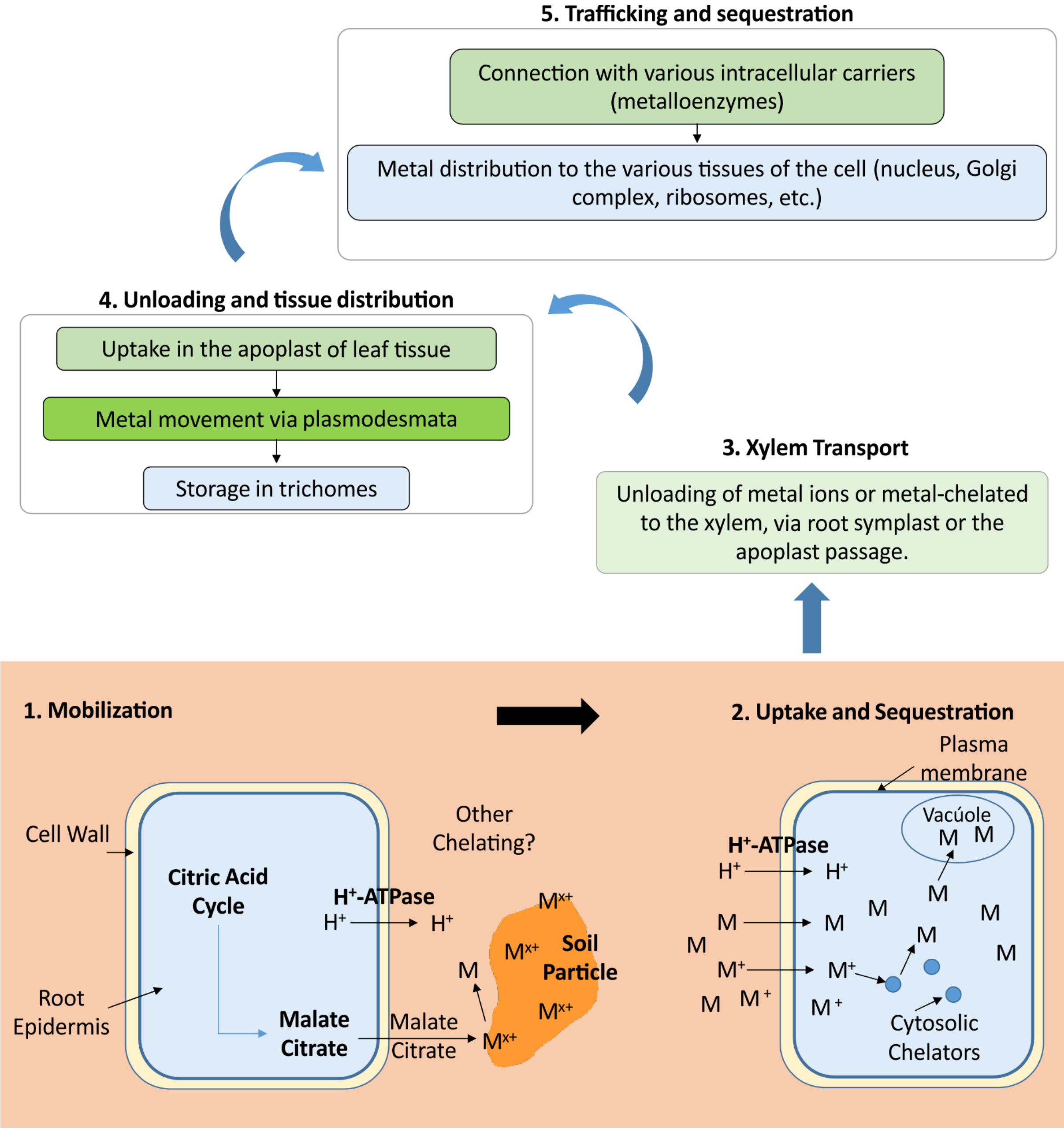

FIGURE 1. Proposal for the molecular mechanism of metal accumulation in the plant. Legend: M: metal. Source: The authors, adapted from CLEMENS et al. (2002).

a. Metal ions are mobilized by the secretion of chelates and by the acidification of the rhizosphere.
b. Absorption of hydrated metal ions or metal-chelate complexes is mediated by several receiving systems in the plasmatic membrane. Metals within the cell are chelated and metal excess is sequestered by transport in the vacuoles.
c. Within the roots, transition metals are transported to the sapling through the xylem. Probably most reach the xylem through the root of the symplast and the apoplast passage may occur at the root´s tip. Metals in the xylem are present as hydrated ions or as metal-chelate complexes.
d. After reaching the leaf´s apoplast, the metals are differentially received by the leaves and move, cell by cell, through the plasmodesmata. Storage seems to occur preferentially in the trichomes.
e. Reception of leaf cells is catalyzed by several intracellular transporters, such as metalcaperons.

The absorption of excess metal by plants causes oxidative stress in its cells (LI et al., 2012) and indirectly concentration decrease of fatty acids, such as palmitic and linolenic acids in *Hydrilla verticillata* when exposed to lead (NESTEROV et al., 2009). Alpha-linolenic acid was drastically reduced in the leaves of *Populus nigra* when developed with lead (LE GUÉDARD et al., 2012).

Plants developed two main mechanisms to develop under oxidative stress (WANG et al., 2011), namely:

1. Enzymatic antioxidant system (mainly represented by catalase, dismutase superoxide, ascorbate peroxidase and glutathione reductase;
2. Non-enzymatic systems which include tocopherols, ascorbic acid and secondary metabolites (phenols and volatiles).

Several toxicological effects may occur when the plant accumulates heavy metals (e.g. lead) in its cells. Hossain et al. (2011) suggest a biochemical and molecular mechanism for the induction of heavy metals to oxidative stress and negative effects in higher plants (Figure 2). Consequently, the heavy metals are first sequestered and stored in the cells, as proposed by Clemens et al. (2002). They interfere in the homeostasis of other essential metals, with damages at molecular levels (proteins and DNA) and the consequent metabolic disorder due to the mal-function of the biomolecules.

The above-mentioned disorder induces oxidative stress in the cells and, may consequently cause perceptible physiological damages, such as growth inhibition of the plant.

Lead-exposed plants may have high concentrations of phenols produced as an enzymatic strategy to cope with metal-caused oxidative stress. Increase in phenol concentrations has been reported by Wang et al. (2011) in *Vallisneria natans* exposed to lead. Evidence exists that increase in phenol concentration may remove metals from the plants´ tissues since it removes reactive oxygen and metal chelation (PAWLIK-SKOWRÓNSKA & BACKOR, 2011).

Toxicological effects on plants

Lead, a non-essential metal for plants, is highly toxic, with a great accumulation capacity in the organism (CHAVES, 2013). Its phytotoxicity depends on concentration, exposure time to the metal, species, organ or plant tissue, causing difficulties in the growth and development of plants (MORAES, 2011). Plants growing on lead-contaminated soils reveal physiological, biochemical and structural effects, such as leaf chlorosis, changes in enzyme activities (RIBEIRO et al., 2015), inhibition or reduction of seed germination (RULEY et al., 2006), inhibition of photosynthesis and modification of anatomic features (PEREIRA et al., 2013), effects on the structure and permeability of the membrane (WÓJCIK & TUKIENDORF, 2014), increases in the number of stomata (PEREIRA et al., 2013), darkening of the radicular system and changes in the water and hormone balance (ROMEIRO et al., 2007).

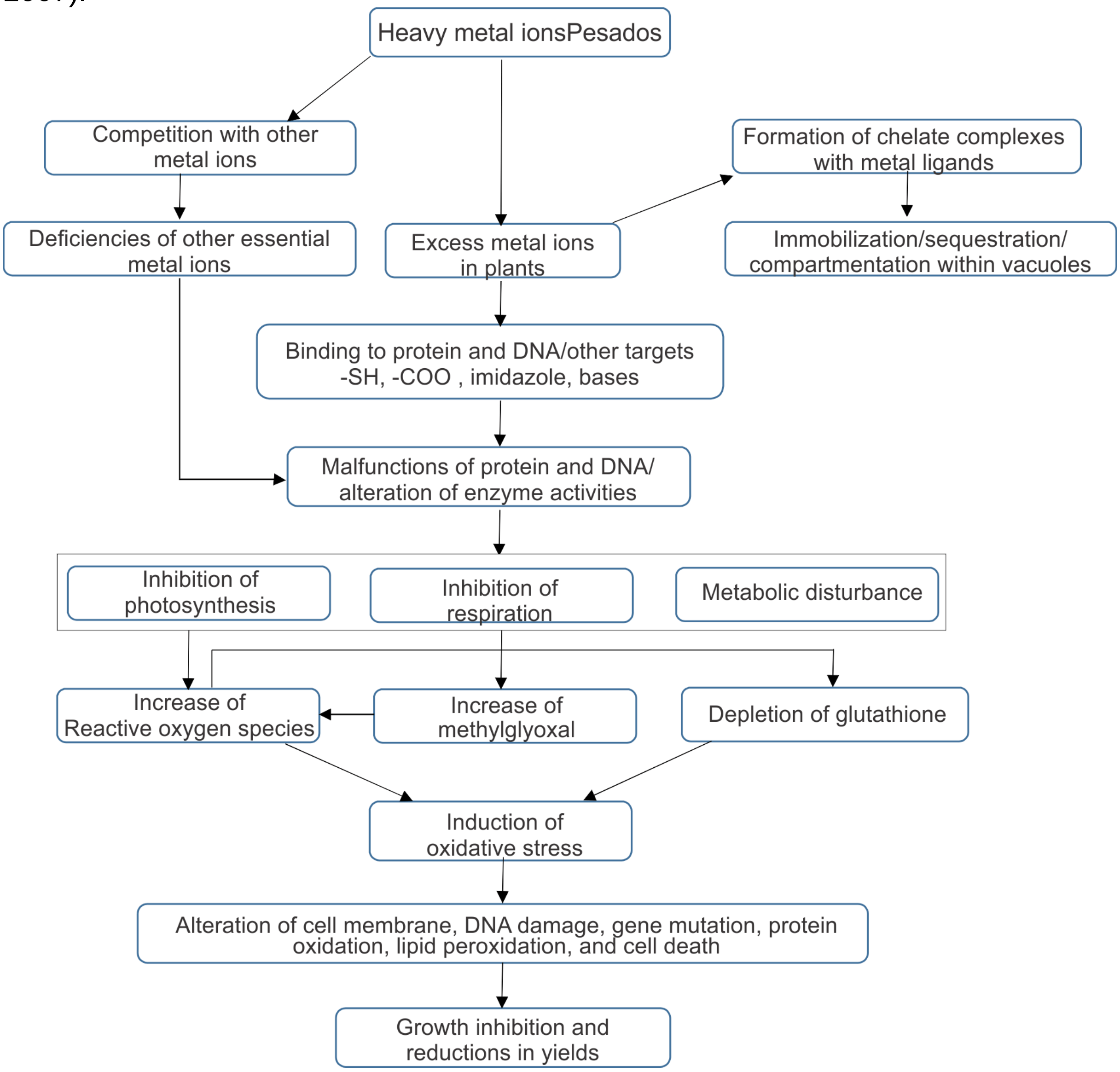

FIGURE 2. Probable biochemical and molecular mechanism of the induction of heavy metal to oxidative stress and negative effects in high plants. Source: Hossain et al. (2011).

Table 1 reports researches on the ecotoxological effects in different vegetal species at different experimental concentrations. Tolerance of these species to lead is variable and, consequently, its effects are negative.

Each vegetal species varies in tolerance or sensitiveness degree to heavy metals and may absorb sufficient amounts to cause damage to plant tissues and its development (SILVA, 2006). Lead tends to accumulate in radicular tissues (SILVA, 2014) and may affect the input of water and nutrition of plants, with a reduction of growth in the root and aerial parts (ROSSATO, 2010; SILVA, 2014).

Photosynthesis is one of the most sensitive factors at the toxic level of lead (GARG & AGGARWAL, 2011) since it causes decrease in photosynthetic rate (LIMA et al., 2013) and in the organization of the chloroplast, with changes in different enzymes and in antioxidants whose function is the protection of vegetal species (ROSSATO, 2010).

The rate of lead absorbed and accumulated in plant tissues is highly variable among species and their varieties and depend on the physiological properties of the culture and environmental factors such as pH, size of soil particles, capacity in cation exchange, organic matter and availability of nutrients (LIMA, 2010a).

Absorption during germination development varies according to differences in seed structure. When the skin is broken, the metal is easily absorbed and accumulated in the meristem regions of the roots and of the hypocotyl with damages to vegetal development (MORAES, 2011). However, the skin may provide a greater protection to the seed in the absorption of lead, as has been perceived in lettuce seeds with the highest tolerance to lead, probably due to cutaneous protection. However, lead inhibited root growth from the concentration of 1.0 mM (PEREIRA et al., 2013; Figura 3).

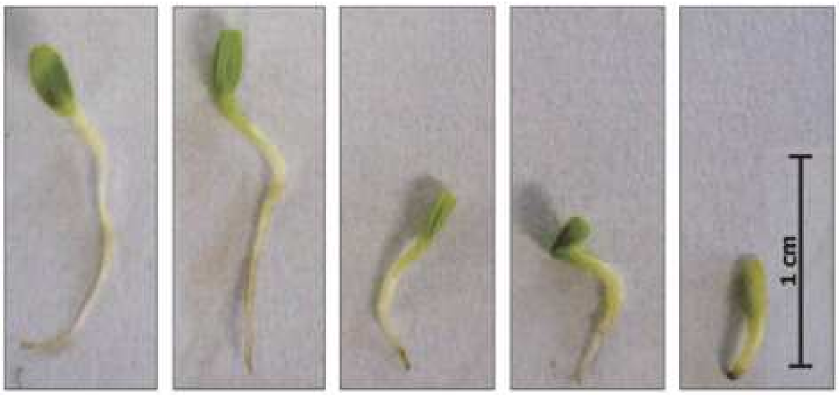

FIGURE 3. Seedlings of *Lactuca sativa* under the effects of lead at concentrations (left to right) 0.0; 0.5; 1.0; 2.0, 5.0 mM of lead. Source: PEREIRA et al. (2013).

Lead is easily absorbed by plants with a reduction in germination percentage, decrease in the velocity index of germination and delay in the growth of seedlings (SHARMA & DUBEY; 2005), coupled to a nutritional reduction in the concentration of several essential elements in plants (LIMA et al., 2013).

Lead concentration varies according to the organ, at the following decreasing order: roots > leaves > stem > flowers > seeds. However, the order may be inverted according to the species. Concentration pattern also varies in the root (SILVA, 2014).

TABLE 1. Lead concentrations caused toxic effects in the development of seedlings of various plant species, reported in the literature.

Espécie	Concentração de Chumbo	Efeitos tóxicos (redução)	Referência
Salsola passerina	0, 50, 150, 300, 600, 800, 1000 mg/L	50 mg/L - germination percentage, germination energy, GSI.	Rui Hu et al. (2012)
Chenopodium album L.	0, 50, 150, 300, 600, 800, 1000 mg/L	50 mg/L - germination energy, GSI, 150 mg/L - germination percentage.	Rui Hu et al. (2012)
Spinacia oleracea L.	0 - 500 mg kg^{-1}	500 mg kg^{-1} - Oxidative stress and proteotoxicity in seedlings.	Wang et al. (2011)
Matricaria chamomilla	0, 5, 30, 60, 120 e 180 mM	60 mM - germination, root growth and shoot, fresh and dry.	Saderi; Zarinkamar, (2012)
Ulmus pumila L.	20, 50 e 90 µM	20 µM - germination,root length.	Đukić et al. (2014)
Brassica rapa var. turnip	1.0, 2.5 e 5.0 g/L	1.0 g/L - GSI. 2.5 g/L - Average of seedling growth, germination percentage.	Siddiqui et al. (2014)
Lactuca sativa L.	0.0, 0.5, 1.0, 2.0 e 5.0 mM	1.0 mM - Growth of seedling. 2.0 mM - Normal seedlings.	Pereira et al. (2013)
Triticum aestivum L.	0, 0.15, 0.3, 1.5 e 3.0 mM	0.3 mM - germination percentage. 1.5 mM - biomass, root growth and leaves esterase. 0.15 mM - protein amount, proline, α-amylase.	Lamhamdi et al. (2011)
Leucaena leucocephala (Lam.)	25, 50, 75, 100 ppm	50 ppm - Percentage germination, root growth. 25 ppm - Dry weight of seedlings.	Shafiq et al., (2008)
Lens culinaris Medic.	0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 e 4.5 mM	0.5 mM - germination percentage, vigor index and length of radicle.	Cokkizgin; Cokkizgin (2010)
Lycopersicon esculentum Mill.	0.25, 0.5 e 0.75 mM	0.5 mM - ESI. 0.25 mM - Seedling length. 0.75 mM - Germination percentage.	Moraes et al., (2014)

GSI: Germination speed Index; ESI: Emergency speed index.

... Continuation of **Table 1**.

Specie	Concentration Lead	Toxic effects (reduction)	Reference
Sinapis arvensis L.	150, 300, 600, 750, 900, 1200, 1500 μM	150 mM - Germination percentage, root length, fresh weight and dry weight. 300 mM - shoot length.	Heidari; Sarani (2011)
Thespesia populnea L.	5, 10, 15, 20, 25 μmol/L	20 mmol/L - Radicle length. 25 mmol/L - Shoot length and dry weight and inhibiting the growth of seedlings.	Kabir et al., (2010)
Phaseolus vulgaris L.	2, 4, 6, 8 g Kg^{-1}	2 g kg^{-1} - Germination percentage, radicle length and shoot dry weight and fresh.	Bhardwaj et al., (2009)
Albizia lebbeck L. Benth	10, 30, 50, 70, 90 μmol/L	10 mmol/L - Germination and seedling length. 30 - Dry biomass. 50 mmol/L - root length.	Farooqui et al., (2009)
Brassica juncea	0.00, 2.50, 10.00, 50.00, 100.00 mg.L^{-1}	50 mg.L^{-1} - Matéria seca das plântulas.	Augusto et al., (2014)
Triticum aestivum L.	200, 500, 1000, 2000 μM	200 μM - Growth of roots and shoots. 2000 μM - Root growth inhibition and shoot.	Dey et al. (2007)

Lead remediation in the environment

Great concern exists in the remediation of lead in the soil. In the face of environmental degradation caused by heavy metals, various methods have been used to remediate soil contamination (Souza et al., 2011), and restore degraded ecosystems (OLIVEIRA, 2010).

Emission decrease by industries through adsorption depends on the use of expensive techniques that employ activated carbon and ion exchange resin as adsorbents, which are difficult to adapt for large scale treatment of residual water (KOBYA et al., 2005).

Metal immobilization by biosorption or precipitation by inorganic or organic changes has already been tested (HE et al., 2013; PARK et al., 2011; TANG et al., 2015). Cleaning and sanitary landfill feature among the techniques suggested for small volumes of highly polluted soil (FEDJE et al., 2013). However, they are e*x situ* techniques which may cause negative effects to the environment and to the ecosystem.

Several studies provided the results of experiments of lead biosorption in effluents from batteries (CHAKRAVARTY et al., 2010), electroplating (MACHADO et al., 2010); gold mining (BENAVENTE et al., 2011), industrial (VIMALA et al., 2011) and laboratory effluents (VIJAYARAGHAVAN & BALASUBRAMANIAN, 2013; VIJAYARAGHAVAN & JOSHI, 2013). However, several techniques are still at a laboratory stage and required adaptation to environmental scale, with variable costs for their development.

Bio-detection and bioremediation are alternatives which are being intensely researched. These techniques comprise the use of microorganisms which maintain resistance and homeostasis when they absorb lead concentrations from the environment (ANSARY et al., 1995) whilst some may detect the presence of lead, for instance, by bioluminescence (JOUANNEAU et al., 2011).

Phytoremediation is an *in situ* technique which causes low environmental impact and may be applied in larger polluted areas. They are, in fact, less expensive but less efficient (PULFORD; WATSON, 2003), utilize organisms and plants with heavy metal absorption capability, removing the soil.

Its several advantages consist in being a permanent solution, low costs, usage of solar energy, recycling of metals and avoidance of soil erosion through drilling (ROSSATO, 2010). It is actually a technique that may be developed by five physiological processes: phytoextraction, phytostabilization, phytodegradation, phytovolatilization and rhyzodegradation (BATISTA, 2013; Table 2).

Several plants accumulate heavy metals and studies are being undertaken to prove their tolerance capacity so that the species may be employed as possible phytoremediation of the metal concerned (OLIVEIRA, 2010). Figure 4 illustrates some species with such capacity.

In fact, several research works have been performed on plant species used as possible lead phytoremediation, such as: *Pistia stratiotes* (OLIVEIRA, 2010), *Leucaena leucocephala* (BOURLEGAT et al., 2008), *Eichhornia crassipes* (PEREIRA, 2010; OLIVEIRA et al., 2014), *Stizolobium aterrimum* (SOUZA et al., 2011), *Pluchea sagittalis* (ROSSATO, 2010), *Ricinus communis* (LIMA, 2010b), *Helianthus annuus* (LIMA, 2010), *Canavalia ensiformis* (ROMEIRO et al., 2007), *Mucuna aterrima* (SANTOS et al., 2012), *Jatropha curcas* (GOUVEIA et al., 2015), *Salvinia auriculata* (ALMEIDA, 2014).

TABLE 2. Description of phytoremediation techniques currently studied for the remediation of heavy metals in the soil.

Physiological Process/ Description
Phytoextraction - It is based on identifying hyperaccumulator plants (PEREIRA, 2010), and the metal accumulation in the aerial part of the plant (Souza et al., 2011). These plants need to have the potential to extract the soil metal, transport to the shoot, accumulate large amounts, fast growing and easily cultivated present (BOURLEGAT et al., 2008).
Phytostabilization - It used the association of plants with Arbuscular mycorrhizal fungi (AMF) AMF that immobilize the contaminant metal roots and soil, reducing the available metal content and contamination to uncontaminated areas (SOUZA et al., 2011).
Phytodegradation - Is to degrade the metal present in the roots and shoots through the anabolism and catabolism held within plant cells by specific enzymes (LIMA, 2010b).
Phytovolatilization - It is based on plant or microorganisms that volatilize the metal, degrading it in the root or after transport throughout the plant, releasing it to the atmosphere.
Rhyzodegradation - Consists of the absorption, concentration and metal precipitation by plant roots (LIMA, 2010b).

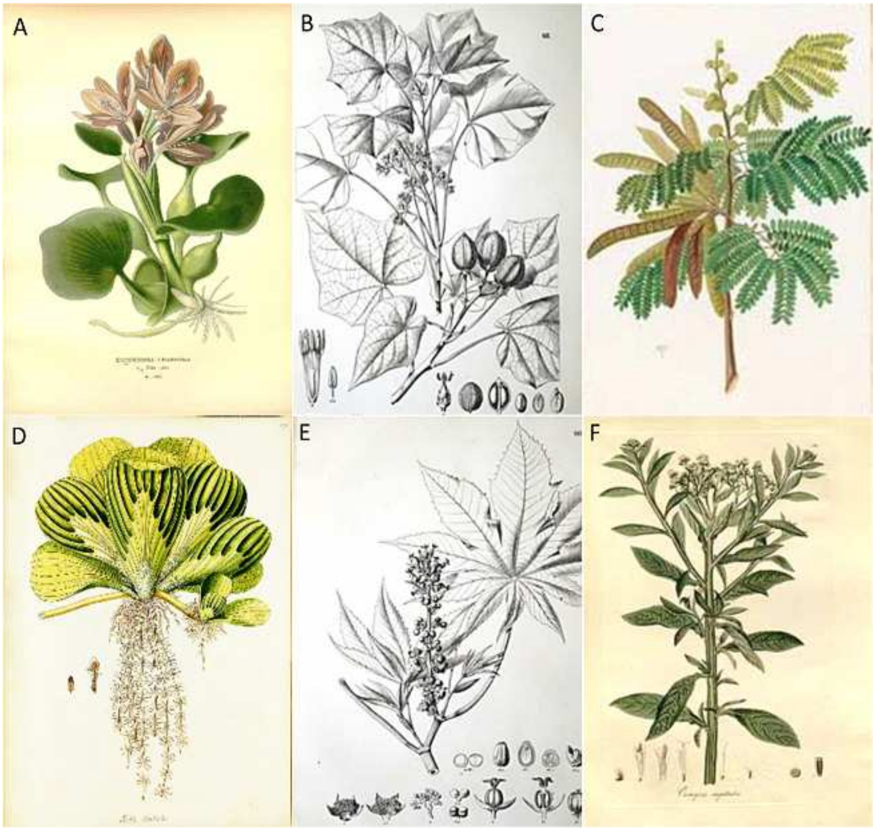

FIGURE 5. Botanic illustrations of some species registered in the literature as probable phytoremediation factors of lead in soils.

Legend: A: *Eichhornia crassipes*; B: *Jatropha curcas* L.; C: *Leucaena leucocephala*; D: *Pistia stratiotes*; E: *Ricinus communis*; F: *Pluchea sagittalis*. Sources: B, E, F: Projeto Flora Brasilensis florabrasiliensis.cria.org.br; A, C, D: plantillustrations.org.

FINAL CONSIDERATIONS

Lead causes several biochemical and molecular processes in plant cells and several studies reported research from its toxic effects on plant development. Some factors favor this toxicology and absorption mainly in the type of species being exposed. Among the plant tissues, root tissues is one of the most accumulate.

Lead can affect the initial establishment of seedlings, causing negative effects on agricultural productivity in soil that has this excess metal. However, some species have shown high tolerance to this metal, being used in phytoremediation study, one of the most promising techniques to remedy areas of soils that are polluted by lead.

REFERENCES

ALCÂNTARA, A. J. D. O.; PIERANDELI, M. A. P.; SOUZA, C. A. D.; SOUZA, J. B. D. Teores de As, Cd, Pb, Cr e Ni e atributos de fertilidade de Argissolo Amarelo distrófico usado como lixão no município de Cáceres, estado de Mato Grosso. **Revista Brasileira de Geociências**, v. 41, n. 3, p. 539-548, 2011.

ALMEIDA, E. L.; MARCOS, F. C. C.; SCHIAVINATO, M. A.; LAGÔA, A. M. M. A.; ABREU, M. F. Crescimento de feijão-de-porco na presença de chumbo. **Bragantia**, v. 67, n. 3, p. 569-576, 2008.

ALMEIDA, G. W. **Avaliação do potencial bioindicador e fitorremediador de *Salvinia auriculata* Aublet na presença de Cádmio e Chumbo.** 2014. 57f. Dissertação (Mestrado em Ecologia Aplicada) - Universidade Federal de Lavras, Lavras, 2014.

ANDRADE, M. G.; MELO, V. F.; GABARDO, J.; SOUZA, L. C. P.; REISSMANN, C. B. Metais pesados em solos de área de mineração e metalurgia de chumbo: II - formas e disponibilidade para plantas. **Revista Brasileira de Ciência do Solo**. v. 33, n. 6, p. 1889-1898. 2009.

ANSARI, A. Z.; BRADNER, J. E.; O'HALLORAN, T. V. DNA-bend modulation in a repressor-to-activator switching mechanism. **Nature**, v. 374, n. 6520, p. 371-375, 1995.

ATSDR - **Agency for Toxic Substances & Disease Registry**. 2008. Disponível em: <http://www.atsdr.cdc.gov/cercla/05list.html>.

AUGUSTO, A. S.; BERTOLI, A. C.; CANNATA, M. G.; CARVALHO, R.; BASTOS, A. R. R. Avaliação dos efeitos tóxicos de Cd e Pb na cultura da mostarda (*Brassica juncea*). **Engenharia Sanitária e Ambiental**, v. 19, n. spe, p. 61-68, 2014.

BATISTA, A. A. **Seleção de espécies com potencial fitorremediador de chumbo.** 2013. 57f. Dissertação (Mestrado em Solos e Qualidade de Ecossistemas**)** Universidade Federal do Recôncavo Baiano, Cruz das Almas, 2013.

BENAVENTE, M.; MORENO, L.; MARTINEZ, J. Sorption of heavy metals from gold mining wastewater using chitosan. **Journal of the Taiwan Institute of Chemical Engineers**, v. 42, n. 6, p. 976-988, 2011.

BERTOLI, A. C. **Efeitos do cádmio e do chumbo no crescimento, translocação e teor de nutrientes tomateiro (*Lycopersicum esculentum*) cultivado em solução nutritiva.** 2011. 95p. Dissertação (Mestrado em Agroquímica) - Universidade Federal de Lavras, Lavras, 2011.

BHARDWAJ, P.; CHATURVEDI, A. K.; PRASAD, P. Effect of enhanced lead and cadmium in soil on physiological and biochemical attributes of *Phaseolus vulgaris* L. **Journal of Natural Sciences**, v. 7, n. 8, p. 63-75, 2009.

BOURLEGAT, J. M. G.; ROSSI, S. C.; CHINO, C. E., SCHIAVINATO, M. A.; LAGÔA, A. M. M. A. Tolerância de *Leucaena leucocephala* (Lam.) de Wit. ao metal pesado chumbo. **Revista Brasileira de Biociências**, v. 5, n. S2, p. 1017-1019, 2008.

CAPELLINI, V. L. M. F.; RODRIGUES, O. M. P. R.; MELCHIORI, L. E.; VALLE, T. G. M. Crianças contaminadas por chumbo: Estudo comparativo sobre desempenho escolar. **Estudos em Avaliação Educacional**, v. 19, n. 39, p. 155-180, 2013.

CHAKRAVARTY, P.; SARMA, N. S.; SARMA, H. P. Removal of lead (II) from aqueous solution using heartwood of Areca catechu powder. **Desalination**, v. 256, n. 1, p. 16-21, 2010.

CHAVES, C. L. **Avaliação das concentrações de metais pesados em áreas de deposições de lixo no Município de Ji-Paraná – Rondônia**. 2013. 63f. Trabalho de conclusão de curso (Bacharel em Engenharia ambiental) - Universidade Federal de Rondônia, Ji-Paraná, 2013.

CLEMENS, S. Molecular mechanisms of plant metal homeostasis and tolerance. **Planta**, v. 212, n. 4, p. 475-486, 2001.

CLEMENS, S.; PALMGREN, M. G.; KRÄMER, U. A long way ahead: understanding and engineering plant metal accumulation. **Trends in plant science**, v. 7, n. 7, p. 309-315, 2002.

COKKIZGIN, A.; COKKIZGIN, H. Effects of lead (PbCl2) stress on germination of lentil (*Lens culinaris* Medic.) lines. **African Journal of Biotechnology**, v. 9, n. 50, p. 8608-8612, 2010.

DEY, S. K.; DEY, J.; PATRA, S.; POTHAL, D. Changes in the antioxidative enzyme activities and lipid peroxidation in wheat seedlings exposed to cadmium and lead stress. **Brazilian Journal of Plant Physiology**, v. 19, n. 1, p. 53-60, 2007.

ĐUKIĆ, M.; ĐUNISIJEVIĆ-BOJOVIĆ, D.; SAMUILOV, S. The influence of cadmium and lead on *Ulmus pumila* L. seed germination and early seedling growth. **Archives of Biological Sciences**, v. 66, n. 1, p. 253-259, 2014.

FAROOQI, Z. R.; IQBAL, M. Z.; KABIR, M.; SHAFIQ, M. Toxic effects of lead and cadmium on germination and seedling growth of *Albizia lebbeck* (L.) Benth. **Pakistan Journal of Botany**, v. 41, n. 1, p. 27-33, 2009.

FEDJE, K. K.; YILLIN, L.; STRÖMVALL, A. Remediation of metal polluted hotspot areas through enhanced soil washing–evaluation of leaching methods. **Journal of environmental management**, v. 128, n. 15, p. 489-496, 2013.

FERNANDES, J. D.; DANTAS, E. R. B.; BARBOSA, J. N.; BARBOSA, E. A. Estudo de impactos ambientais em solos: o caso da reciclagem de baterias automotivas usadas, tipo chumbo-ácido. **Revista Brasileira de Gestão e Desenvolvimento Regional**, v. 7, n. 1, p. 231-255, 2011.

GARG N, AGGARWAL N. Effects of interactions between cadmium and lead on growth, nitrogen fixation, phytochelatin, and glutathione production in mycorrhizal *Cajanus cajan* (L.) Millsp**. Journal of Plant Growth Regulation**, v. 30, n. 3, p. 286-300, 2011.

GERHARDSSON, L.; OSKARSSON, A.; SKERFVING, S. CHUVA ÁCIDA—EFEITOS SOBRE OLIGOELEMENTOS E A SAÚDE HUMANA**. InterfacEHS-Revista de Saúde, Meio Ambiente e Sustentabilidade**, v. 7, n. 1, p. 64-74, 2012.

GONÇALVES, M. F. **Variação temporal e espacial da presença dos metais pesados (Cd, Cr, Ni, Pb, Zn) na bacia do rio Barigüi e identificação de suas fontes potenciais.** 2009. 152p. Dissertação (Mestrado em Engenharia de Recursos Hidrícos e Ambientais) - Universidade Federal do Paraná, Curitiba, 2009.

GOUVEIA, A. F.; MACRUZ, P. D.; ARAÚJO, J. H. B. Fitorremediação de solos contaminados com chumbo utilizando *Jatropha curcas* L. **Blucher Chemical Engineering Proceedings**, v. 1, n. 2, p. 8213-8219, 2015.

GRIGOLETTO, T. L. B. **Chumbo na água de consumo de Ribeirão Preto (SP): fatores químicos, físicos e possíveis correlações com a contaminação de crianças.** 2011. 83p. Dissertação (Mestrado em Química) - Universidade de São Paulo, São Paulo, 2011.

GRIGOLETTO, T. L.; FUZARI, B. H.; ANDRADE, A. R.; CAMPOS, M. L. A.; GERLACH, R. F.; SANTOS, J. E. T. Fatores químicos e físicos que afetam a contaminação por chumbo e cobre em água potável: uma abordagem para o estudo de caso em química analítica. **Química Nova**, v. 35, n. 10, p. 1-7, 2012.

HE, M.; SHI, H.; ZHAO, X.; YU, Y.; QU, B. Immobilization of Pb and Cd in contaminated soil using nano-crystallite hydroxyapatite. **Procedia Environmental Sciences**, v. 18, p. 657-665, 2013.

HEIDARI, M.; SARANI, S. Effects of lead and cadmium on seed germination, seedling growth and antioxidant enzymes activities of mustard (*Sinapis arvensis* L.). **ARPN Journal of Agricultural and Biological Science**, v. 6, n. 1, p. 44-47, 2011.

HOSSAIN, M. A.; PIYATIDA, P.; SILVA, J. A. T.; FUJITA, M. Molecular Mechanism of Heavy Metal Toxicity and Tolerance in Plants: Central Role of Glutathione in Detoxification of Reactive Oxygen Species and Methylglyoxal and in Heavy Metal Chelation. **Journal of Botany**, v. 2012, p. 1-37, 2012.

HU, R.; SUN, K.; SU, X.; PAN, Y.; ZHANG, Y.; WANG, X. Physiological responses and tolerance mechanisms to Pb in two xerophils: *Salsola passerina* Bunge and *Chenopodium album* L. **Journal of Hazardous Materials**, v. 205-206, p. 131-138, 2012.

JOUANNEAU, S.; DURAND, M. J.; COURCOUX, P.; BLUSSEAU, T.; THOUAND, G. Improvement of the identification of four heavy metals in environmental samples by using predictive decision tree models coupled with a set of five bioluminescent bacteria. **Environmental science & technology**, v. 45, n. 7, p. 2925-2931, 2011.

KABIR, M.; IQBAL, M. Z.; SHAFIQ, M.; FAROOQI, Z. R. Effects of lead on seedling growth of *Thespesia populnea* L. **Plant, Soil and Environment**, v. 56, n. 4, p. 194-199, 2010.

KEMERICH, P. D. C.; FLORES, C. E. B.; BORBA, W. F.; GERHARDT, A. E.; FLORES, B. A.; RODRIGUES, A. C.; BARROS, G. Indicativo de contaminação ambiental por metais pesados em aterro sanitário. **Revista Monografias Ambientais**, v. 13, n. 4, p. 3744-3755, 2014.

KLEIN, F. C.; HOEHNE, L. Determinação de chumbo em solo de uma antiga fábrica de acumuladores elétricos e proposta de remediação. **Destaques Acadêmicos**, v. 6, n. 4, p. 66-75, 2015.

KOBYA, M.; DEMIRBAS, E.; SENTURK, E.; INCE, M. Adsorption of heavy metal ions from aqueous solutions by activated carbon prepared from apricot stone. **Bioresource technology**, v. 96, n. 13, p. 1518-1521, 2005.

LAMHAMDI, M., BAKRIM, A., AARAB, A., LAFONT, R., SAYAH, F. Lead phytotoxicity on wheat (*Triticum aestivum* L.) seed germination and seedlings growth. **Comptes Rendus Biologies**, v. 334, n. 2, p. 118-126, 2011.

LE GUÉDARD, M.; FAURE, O.; BESSOULE, J-J. Early changes in the fatty acid composition of photosynthetic membrane lipids from *Populus nigra* grown on a metallurgical landfill. **Chemosphere**, v. 88, n. 6, p. 693-698, 2012.

LI, X.; YANG, Y.; ZHANG, J.; JIA, L.; LI, Q.; ZHANG, T.; QIAO, K.; MA, S. Zinc induced phytotoxicity mechanism involved in root growth of *Triticum aestivum* L. **Ecotoxicology and environmental safety**, v. 86, p. 198-203, 2012.

LIMA, A. M. **Avaliação do potencial fitorremediador da mamona (*Ricinus communis* L.) e girassol (*Helianthus annuus* L.) quanto à remoção de chumbo e tolueno em efluentes sintéticos.** 2010. 110f. Tese (Doutorado em Engenharia Química) - Universidade Federal do Rio Grande do Norte, Natal, 2010b.

LIMA, F. S.; NASCIMENTO, C. W. A.; ACCIOLY, A. M. A.; SOUSA, C. S.; FILHO, F.

F. C. Bioconcentração de chumbo e micronutrientes em hortaliças cultivadas em solo contaminado**. Revista Ciências Agronômica**, v. 44, n. 2, p. 234-241, 2013.

LIMA, F. S. **Bioconcentração de chumbo e zinco em partes comestíveis de hortaliças cultivadas em solos contaminados.** 2010. 89f. Tese (Doutorado em Ciência do Solo) - Universidade Federal Rural de Pernambuco, Recife, 2010a.

MACHADO, M. D.; SOARES, H. M. V. M.; SOARES, E. V. Removal of chromium, copper, and nickel from an electroplating effluent using a flocculent brewer's yeast strain of Saccharomyces cerevisiae. **Water, Air, & Soil Pollution**, v. 212, n. 1-4, p. 199-204, 2010.

MAZZUCO, K. T. M. **Uso da *Canavalia ensiformis* como fitorremediador de solos contaminados por chumbo.** 2008. 187p. Tese (Doutorado em Engenharia Química) - Universidade Federal de Santa Catarina, Florianópolis, 2008.

MORAES, C. L. **Alterações bioquímicas, fisiológicas e ultra estruturais em sementes e plantas de tomate expostas ao chumbo.** 2011. 70f. Tese (Doutorado em Fisiologia Vegetal) - Universidade Federal de Pelotas, Pelotas, 2011.

MORAES, C. L.; MARINI, P.; FERNANDO, J. A., MORAES, D. M., CASTRO, L. A. S.; LOPES, N. F. Alterações fisiológicas e ultraestruturais de plântulas de tomate induzidas por chumbo. **IHERINGIA, Série Botânica**, v. 69, n. 2, p. 313-322, 2014.

NESTEROV, V. N.; ROZENTSVET, O. A.; MURZAEVA, S. V. Changes in lipid composition in the tissues of fresh-water plant *Hydrilla verticillata* induced by accumulation and elimination of heavy metals. **Russian Journal of Plant Physiology**, v. 56, n. 1, p. 85-93, 2009.

OLIVEIRA, A. P.; ESPINOZA-QUIÑONES, F. R.; MÓDENES, A.; BRAGIÃO, M.; BEZERRA, I. Avaliação da influência do fósforo na bioacumulação do chumbo pela *Eichhornia crassipes*. **Blucher Chemical Engineering Proceedings**, v. 1, n. 1, p. 539-544, 2014.

OLIVEIRA, C. **Características morfoanatômicas e fisiológicas na avaliação do potencial bioindicador e fitorremediador de *Pistia stratiotes* L. na presença de cádmio, chumbo e arsênio.** 2010. 163p. Dissertação (Mestrado em Agronomia) - Universidade Federal de Lavras, Lavras, 2010.

OLIVEIRA, L. R. **Metais pesados e atividade enzimática em Latossolos tratados com lodo de esgoto e cultivados com milho.** 2008. 108f. Tese (Doutorado em Agronomia) - Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinária, Jaboticabal, 2008.

OLIVEIRA, M. R. **Investigação da contaminação por metais pesados da água e do sedimento de corrente nas margens do rio São Francisco e tributários, a jusante da represa da CEMIG, no município de Três Marias, Minas Gerais.** 2007. 149p. Tese (Doutorado em Geologia) - Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, 2007.

PARK, J.H.; LAMB, D.; PANEERSELVAM, P.; CHOPPALA, G.; BOLAN, N.; CHUNG, J. W. Role of organic amendments on enhanced bioremediation of heavy metal (loid) contaminated soils. **Journal of Hazardous Materials**, v. 185, n. 2, p. 549-574, 2011.

PAWLIK-SKOWROŃSKA, B.; BAČKOR, M. Zn/Pb-tolerant lichens with higher content of secondary metabolites produce less phytochelatins than specimens living in unpolluted habitats. **Environmental and Experimental Botany**, v. 72, n. 1, p. 64-70, 2011.

PEREIRA, F. J. **Características anatômicas e fisiológicas de aguapé e índice de fitorremediação de alface d´ água cultivados na presença de arsênio, cádmio e chumbo.** 2010. 116p. Tese (Doutorado em Agronomia) - Universidade Federal de Lavras, Lavras, 2010.

PEREIRA, M. P.; PEREIRA, F. J.; RODRIGUES, L. C. A.; BARBOSA, S.; CASTRO, E. M. Fitotoxicidade do chumbo na germinação e crescimento inicial de alface em função da anatomia radicular e ciclo celular. **Revista Agro@ mbiente On-line**, v. 7, n. 1, p. 36-43, 2013.

PINO, G. A. H. **Biossorção de metais pesados utilizando pó da casca de coco verde (*Cocos nucifera*).** 2005. 113f. Dissertação (Mestrado em Engenharia Metalúrgica) - Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2005.

POLETTI, G. D; ETHUR, E. M.; HOEHNE, L. Determinação de cádmio e chumbo em solos usados em plantações de erva-mate sem e com diferentes tipos de manejo na região sul do país. **Destaques Acadêmicos**, v. 6, n. 4, p. 59-65, 2014.

PRESTON, W.; NASCIMENTO, C. W. A.; BIONDI, C. M.; JUNIOR, V. S. S.; SILVA, W. R.; FERREIRA, H.A. Valores de referência de qualidade para metais pesados em solos do Rio Grande do Norte. **Revista Brasileira De Ciência do Solo**, v. 38, n. 3, p. 1028-1037, 2014.

PULFORD, I. D.; WATSON, C. Phytoremediation of heavy metal-contaminated land by trees—a review. **Environment international**, v. 29, n. 4, p. 529-540, 2003.

RANGEL, O. J. P.; SILVA, C. A.; BETTIOL, W.; DYNIA, J. F. Efeito de aplicações de lodos de esgoto sobre os teores de metais pesados em folhas e grãos de milho. **Revista Brasileira de Ciência do Solo**, v. 30, n. 3, p. 583-594, 2006.

RIBEIRO, E. S.; PEREIRA, M. P.; CASTRO, E. M.; BARONI, G. D. R.; CORRÊA, F. F.; PEREIRA, F. J. Relações da anatomia radicular na absorção, no acúmulo e na tolerância ao chumbo em *Echinodorus grandiflorus*. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 19, n. 6, p. 605-612, 2015.

ROMEIRO, S.; LAGOA, A. M. M. A.; FURLANI, P. R.; ABREU, C. D.; PEREIRA, B. F. F. Absorção de chumbo e potencial de fitorremediação de C*anavalia ensiformes* L. **Bragantia**, v. 66, n. 2, p. 327-334, 2007.

ROSSATO, L. V. **Efeitos bioquímicos e fisiológicos do chumbo em plantas de quitoco (*Pluchea sagittalis*): Possível papel fitorremediador.** 2010. 83p. Dissertação (Mestrado em Bioquímica toxicológica) - Universidade Federal de Santa Maria, Santa Maria, 2010.

RULEY, A. T.; SHARMA, N. C.; SAHI, S. V.; SINGH, S. R.; SAJWAN, K. S. Effects of lead and chelators on growth, photosynthetic activity and Pb uptake in *Sesbania drummondii* grown in soil. **Environmental Pollution**, v. 144, n. 1, p. 11-18, 2006.

SADERI, S.; ZARINKAMAR, F. The effect of different Pb and Cd concentrations on seed germination and seedling growth of *Matricaria chamomilla*. **Advances in Environmental Biology**, v. 6, p. 1940-1943, 2012.

SANTOS, C. H.; OLIVEIRA GARCIA, A. L.; CALONEGO, J. C.; TIRITAN, C. S.; RIGOLIN, I. M.; NOVAIS SPÓSITO, T. H. Utilização da mucuna preta (*Mucuna aterrima* Piper & Tracy) para a fitorremediação de solo contaminado por chumbo. **Revista Agro@mbiente On-line**, v. 6, n. 3, p. 215-221, 2012.

SHAFIQ, M.; IQBAL, M. Z.; MOHAMMAD, A. Effect of lead and cadmium on germination and seedling growth of *Leucaena leucocephala*. **Journal of Applied Sciences and Environmental Management**, v. 12, n. 3, p. 61-66, 2008.

SHARMA, P.; DUBEY, R. S. Lead toxicity in plants. **Brazilian journal of plant physiology**, v. 17, n. 1, p. 35-52, 2005.

SIDDIQUI, M. M.; ABBASI, B. H.; AHMAD, N.; ALI, M.; MAHMOOD, T. Toxic effects of heavy metals (Cd, Cr and Pb) on seed germination and growth and DPPH-scavenging activity in *Brassica rapa* var.turnip. **Toxicology and Industrial Health**, v. 30, n. 3, p. 238-249, 2014.

SILVA, M. A. V. **Avaliação fisiológica da aroeira (*Schinus terebinthifolius* Raddi) sob déficit hídrico com vista para o reflorestamento.** 2007. 84p. Dissertação (Mestrado em Ciências Florestais) - Universidade Federal Rural de Pernambuco, Recife, 2007.

SILVA, M. L. S. **Avaliação do comportamento de elementos traços essenciais e não essenciais em solo contaminado sob cultivo de plantas**. 2006. 112p. Tese (Doutorado em Agronomia) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, 2006.

SILVA, M. L. S.; VITTI, G. C.; TREVIZAM, A. R. Concentração de metais pesados em grãos de plantas cultivadas em solo com diferentes níveis de contaminação. **Pesquisa Agropecuária Brasileira**, v. 42, n. 4, p. 527-535, 2007.

SILVA, P. R. C. **Avaliação da fito-e genotoxicidade do chumbo em *Lactuca sativa* L.** 2014. 180p. Dissertação (Mestrado em Genética Molecular Comparativa e Tecnológica) - Universidade de Trás-os-Montes e Alto Douro, Vila Real, 2014.

SOUZA, L. A.; ANDRADE, S. A. L.; SOUZA, S. C. R.; SCHIAVINATO, M. A. Tolerância e potencial fitorremediador de *Stizolobium aterrimum* associada ao fungo micorrízico arbuscular *Glomus etunicatum* em solo contaminado por chumbo. **Revista Brasileira de Ciência do Solo**, v. 35, n. 4, p. 1441-1451, 2011.

SOUZA, L. C. P.; REISSMANN, C. B. Metais pesados em solos de área de mineração e metalurgia de chumbo. I - Fitoextração. **Revista Brasileira de Ciência do Solo**, v. 33, n. 6, p. 1879-1888, 2009.

TANG, X., LI, X., LIU, X., HASHMI, M. Z., XU, H. J., BROOKES, P. C. Effects of inorganic and organic amendments on the uptake of lead and trace elements by *Brassica chinensis* grown in an acidic red soil. **Chemosphere**, v. 119, p. 177-183, 2015.

TANGAHU, B. V.; ABDULLAH, S. R. S.; BASRI, H.; IDRIS, M.; ANUAR, N.; MUKHLISIN, M. A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation**. International Journal of Chemical Engineering**, v. 2011, p. 1-31. 2011.

VIJAYARAGHAVAN, K.; BALASUBRAMANIAN, R. A comparative evaluation of sorbents for the treatment of complex metal-bearing laboratory wastewaters. **Journal of Environmental Chemical Engineering**, v. 1, n. 3, p. 473-479, 2013.

VIJAYARAGHAVAN, K.; JOSHI, U. M. Hybrid Sargassum-sand sorbent: A novel adsorbent in packed column to treat metal-bearing wastewaters from inductively coupled plasma-optical emission spectrometry. **Journal of Environmental Science and Health, Part A**, v. 48, n. 13, p. 1685-1693, 2013.

VIMALA, R.; DAS, N. Mechanism of Cd (II) adsorption by macrofungus *Pleurotus platypus*. **Journal of Environmental Sciences**, v. 23, n. 2, p. 288-293, 2011.

WANG, C.; GU, X.; WANG, X.; GUO, H.; GENG, J.; YU, H.; SUN, J. Stress response and potential biomarkers in spinach (*Spinacia oleracea* L.) seedlings exposed to soil lead. **Ecotoxicology and environmental safety**, v. 74, n. 1, p. 41-47, 2011.

WEI, W., LIU, X., SUN, P., WANG, X., ZHU, H., HONG, M., MAO, Z., ZHAO, J. Simple whole-cell biodetection and bioremediation of heavy metals based on an engineered lead-specific operon. **Environmental science & technology**, v. 48, n. 6, p. 3363-3371, 2014.

WÓJCIK, M.; TUKIENDORF, A. Accumulation and tolerance of lead in two contrasting ecotypes of *Dianthus carthusianorum*. **Phytochemistry**, v. 100, p. 60-65, 2014.