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REVIEW ARTICLE

Lead toxicity in plants and phytoremediation potential of aromatic plants for lead contaminated soils

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Key Words

Aromatic plants
Lead (Pb)
Phytoremediation
Toxicity
Tolerance

ABSTRACT

Lead contamination and subsequent degradation of the affected soil is a global environmental issue. Besides the natural weathering processes, the chief ways in which of lead contaminates the environment are anthropogenic. The plants which grow on such lead contaminated soils can uptake the heavy metal and translocate it to the various parts both in the intracellular and extracellular fashion. Lead toxicity can affect the overall plant health as it impacts basic physiological and metabolic processes such as germination, uptake of nutrients and minerals, photosynthesis, respiration, oxidative metabolism, mitosis etc. Plants in response to this toxicity can develop a certain degree of tolerance via passive and inducible mechanisms. These mechanisms have been exploited in the new era technology of phytoremediation which aims at a sustainable cleansing of lead contaminated soils by using plants. Aromatic plants because of their low risk of contamination in products consumption and a high demand over supply aspects are a suitable choice of plants that can be used for phytoremediation. This review addresses the aspects of lead contamination and its sources, the uptake of lead by plants, lead toxicity in plants, and the consequent tolerance developed as well as the potential and advantages of using aromatic plants for phytoremediation of soils which are contaminated with lead.

INTRODUCTION

Numerous organic and inorganic pollutants have caused environmental degradation, which has become a critical problem that threatens global ecosystems and the environmental sanctity worldwide (Kanawade et al., 2010). Of all the inorganic contaminants, heavy metals have long been addressed as potential soil pollutants. As a result of agro-economic and industrial processes, contamination of the soil by heavy metals has become a matter of grave concern (Sharma and Dubey, 2005). Since these heavy metals are naturally found in the lithosphere owing to the pedogenic weathering activities, at minute quantities (< 1000 mg kg^{-1}) they are not a threat to the environment and plants (Wuana and Okieiemn,

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2011). Various human activities such as mining, electroplating, smelting, steel industry, fuel burning, inorganic fertilizer and pesticide use have raised the concentration of these heavy metals in the environment (Tchounwou et al., 2012). Plants grown on metal-polluted soils absorb these heavy metals (Yang et al., 2006), which in turn cause the accumulation of heavy metals at various trophic levels in the food web as they cannot be metabolized (Farid et al., 2017).

In terms of toxicity, lead (Pb) stands second to arsenic (Zulfikar et al., 2019). Pb contamination has resulted mainly from smelting and mining operations, paints containing lead, explosives and gasoline as well as the disposal of industrial sewage effluents containing Pb, in addition to natural weathering processes (Chaney and Ryan, 1994). Due to natural and anthropogenic factors, the accumulation of Pb in the soil can cause serious problems for the soil biota and the environment, which is of great concern to the scientific community (Mitra et al., 2020).

While lead is not an important plant mineral, it is readily absorbed and stored in various parts of the plant (Sharma and Dubey, 2005). Lead uptake by plants is controlled primarily by parameters such as pH of the soil, soil particle size, cation exchangeability, exudation from roots, and many other physiochemical dependent variables (Hadi and Azeez, 2015). Experimental studies by Meyer et al., (2008) on the uptake and localization of Pb in *Brassica juncea,* an ethnomedicinal plant, revealed some characteristic features of the root uptake of Pb as well as its extracellular and intracellular distribution.

Lead phytotoxicity can severely impact the plant, but the degree of toxicity is dependent on both concentration and time (Zulfiqar et al., 2019). Lead is often considered as a slow-acting and subtle protoplasmic poison (Sharma and Dubey, 2005). High lead concentrations can manifest in the forms of symptoms, including growth retardation (stunted growth), negative effects on photosynthesis (chlorosis), root blackening etc. (Hadi and Aziz, 2015). Lead (Pb) is capable of inhibiting photosynthesis, disrupting the balance of nutrient uptake, plant-water relationship, altering hormonal status and influencing the structure of the membrane and its permeability (Hadi and Aziz, 2015). It may also contribute to oxidative stress and genotoxic effects, including damage to DNA and mitosis defects.

Plants also develop lead tolerance in response to lead toxicity. Lead tolerance is correlated with the plant's ability to limit the cell walls, osmolyte synthesis and activation of antioxidant protection systems (Sharma and Dubey, 2005). Lead occurs in many edible crops but in restricted amounts and its quantity is greatly increased by growing crops on lead contaminated soils. Several strategies are used to restore soils polluted with Pb, but the primary aim of each technique is basically to save the environment (Martin and Ruby, 2004). There are three fundamental approaches to remediate lead-polluted soils: physical, chemical and biological (Yao et al., 2012). Remediation using biological methods is a viable and promising solution that is not only effective but also economical (Zulfiqar et al., 2019). Since the dawn of the last decade, different environmentalists have been researching the usage of aromatic plants for phytoremediation of Pb-contaminated soils. By virtue of not being connected to the food chain in a direct manner, they provide a low risk assessment of the contamination of their final products by heavy metals (Zheljazkov and Nielsen, 1996a; Zheljazkov and Warman 2004; Pandey et al., 2009). Certain aromatic plants such as vetiver, lemon grass, basil, etc. have been found successful in the phytoremediation of Pb either by being good biosorbents, accumulators or stabilizers, (Yang et al., 2003; Prasad et al., 2010; Hassan, 2016).

This review addresses the aspects of sources of Pb contamination, its uptake by the plant and localization with special reference to a case study on *Brassica juncea* for the uptake and localization by the root system, the physiological, biochemical and cytological effects of lead on plants, lead tolerance developed by plants and the phytoremediation of lead contaminated soils with a subsequent discussion on the potential and advantages of aromatic plants for the same.

SOURCES OF LEAD CONTAMINATION

Lead is widely spread in the environment (Sturge and Barrie, 1989; Sungmin et al., 1994; Ingemar et al., 2000; Branval et al., 2001; Pompeani et al., 2013). It is a significant pollutant in both terrestrial and marine habitats (Sharma and Dubey, 2005). Volcanic explosions and forest fires are chief sources of natural lead contamination. Human activities are non-natural sources, primarily referring to lead pollution from manufacturing and transport (Zhang et al., 2015). In addition to the natural weathering processes, exhaust gases from vehicles, factory emissions, effluents from storage batteries, industries, Pb mining and smelting, metal plating and finishing operations, fertilizers, pigment additives and gasoline are sources of lead pollution (Elick et al., 1999). As lead compounds are major automotive pollutants, plants that grow near highways are usually exposed to more Pb and are thus more affected than plants in other locations (Paivoke, 2002). Typically, the soils affected by Pb contain the metal in the range of 400-800 mg/kg (Angelon and Bini, 1992).

UPTAKE AND SUBCELLULAR ACCUMULATION

Lead enters the plants from soil and aerosol sources. Leaves absorb Pb from the atmosphere, the extent of which depends upon the leaf morphology. Downy leaves are reported to absorb heavy metals from the atmosphere (Godzik et al., 1993). Pb-accumulating capacity of leaves also varies with the age of the leaves for example, senescing leaves are observed to contain more Pb than young leaves (Lane and Martin 1997). Most of the lead absorbed by plants from the soil remains in the roots (Kumar et al., 1995). Lead is usually present in the upper layers of the soil; hence it is not possible to precisely measure how much lead is available for the plants to uptake. Depending on the soil conditions such as soil particle size and plant conditions such as root surface area, mycorrhization, root exudates and transpiration rate etc., the availability of lead varies (Kumar et al., 1995). At the root surface, lead ions bind to carboxyl groups of mucilage uronic acids, which can prevent its uptake by roots but when mucilage is bio-degraded the lead ions are released (Morel et al., 1986). Soil microbes can also affect availability of Pb by solubilization and biosorption. Ectomycorhizae have been shown to influence the uptake and transport of Pb (Marchener et al., 1996). Dicotyledonous plants have been reported to be more efficient in accumulating lead in the root system than monocotyledonous plants (Huang et al., 1996).

The localization of Pb is maximum observed in inter-cellular spaces and vacuoles; but traces of the metal have also been reported in endoplasmic reticulum, dictyosomes and other such vesicles. Minor quantities of Pb that reaches the nucleus, mitochondria and chloroplasts can exert toxic effects there (Lane and Martin, 1977). Pinocytotic vacuoles have been reported in many plant species, formed by plasmalemma's invagination, which help in the sequestration of extra metal ions to protect the cell contents from toxic impacts of lead. Larger particles of lead usually appear to occupy the cell wall in the region near plasmodesmata, whereas smaller lead particles can get deposited within the cell wall towards the boundaries (Silverberg, 1975).

Case Study : Uptake and localization of Pb in the root system of Brassica juncea:

a) *Plant description and medicinal value*

The common name of *Brassica juncea* is Rajika and it belongs to the family Brassicaceae. The seeds of this plant are called brown mustard and are of great value in folk medicine (Mishra et al., 2012). This plant, is one of the major oil seed crops cultivated throughout in India; particularly in Bihar, Bengal and Uttar Pradesh. It is a large annual branch, growing up to a height of 0.6-1 meters. The leaves are broadly ovate, dentate, while the lower ones are lyrate and slightly hispid, while the upper ones are lanceolate, all stalked, dark green. In corymbose racemes, the flowers are stalked, light yellow. The fruits are siliqua and linearly oblong. Brownish-red, small, tiny seeds are the seeds (Alqasoumi, 2010).

The herb is traditionally used as a remedy for arthritis, foot ache, lumbago, and rheumatism, while its oil is used for the treatment of skin eruptions and ulcers. The seeds are used in China for the treatment of tumours, while they are used in the treatment of abscesses, lumbago, colds, rheumatism, and stomach disorders in Korea. The root is utilized in Africa as a galactagogue. Ingestion can provide a mosquito repellent odour. The volatile oil is known to be aperitif and tonic and is used as a counterirritant and stimulant. The plant is used as an antisyphilitic emmenagogue in Java (Ouyang et al., 2002).

b) *Brassica juncea* as a potential accumulator of Pb

Many studies have established that *B. juneca* is capable of accumulating significant quantities of heavy metals when either grown in soil or hydroponically (Kumar et al., 1995). The work done by Meyer et al., (2008) showed that roots of *B. juncea* grown through hydroponic method using different concentrations of Pb solution had much more concentration than the shoots. In the cell walls, lead can strongly bind to the carboxyl groups of carbohydrates such as galacturonic acid and glucuronic acid (Rudakova et al., 1998).

c) Characteristic features of the Pb uptake and translocation in the roots

The uptake of Pb by plants was found to be similar to other heavy metals such as cadmium, arsenic, nickel etc. (Meyer et al., 2008). Four characteristic features of lead distribution in the root tissues of B. *juneca* were identified by Meyer et al., (2008):

i. Highest amount of lead was in the root tip in all the cells.
ii. The presence of intracellular deposits within the elongation zone was less frequent.
iii. A progressive decrease in lead concentration with increasing distance from the root apex.
iv. An important barrier to the passage of Pb into the vascular system is the endodermal cell layer and associated casparian strip. This may be the reason why the metal in the roots accumulates more than the shoots.

d) Distribution of Pb in the extracellular space

On the outer surface of the root, inside the cell wall and middle lamella, dense deposits are present and close to the plasma membrane, mainly due to the anionic sites to which divalent cations bind. In any region, the deposits may be amorphous, punctuate and or needle shaped. These predominate at locations away from root tip (Meyer et al., 2008).

e) Intracellular distribution of Pb

Just beyond the cell membrane, widely dispersed through the cytoplasm, and encircling tonoplasts, lead particles are contained. Endocytosis of Pb into specialized vacuoles is indicated in the study. It is significant and most common at the root tip, which is an intriguing fact, as there is no nutritional role of Pb (Meyer et al., 2008) Numerous membrane transport proteins that regulate the flow of critical micronutrients have been identified in plant cells (Clemens, 2001), which may also transport the toxic metals. Huang et al., (1996) found that voltage gated Ca-channels in the plasma membrane of wheat roots were substantially inhibited by lead, which can be due to the competitive transport of lead through these channels.

PHYSIOLOGICAL, BIOCHEMICAL AND CYTOLOGICAL EFFECTS OF Pb TOXICITY ON PLANTS

Heavy metals such as lead can significantly alter the overall plant developmental aspects. In the case of the level of lead in the agriculture soil exceeds the critical values of 50-300 mg/kg, as suggested by World Health Organization in 1996, morphological, physiochemical, biochemical and even cytological processes are severely affected (Kushwaha et al., 2018).

a) Effect of Pb on seed germination and early plant growth

Heavy metals, by direct or indirect means, have inhibitory effects on seed germination. By having effects on the activity of polyphenol oxidases and peroxidases and thus affecting the oxidizing properties of the roots, Pb toxicity may delay the emergence of radicles (Sethy et al., 2013; Singh et al., 2011). Pb has been reported to potentially interfere with the enzymes which are essential for germination of seeds, such as it affects the amylase and protease activities (Senger et al., 2009).

Lead contamination not only affects seed germination, it even relates to substandard seedling growth because of its toxic impacts on the synthesis of photosynthetic pigments, growth of roots, transpiration and division of cells. Electron microscopic techniques revealed several lead-induced alterations in the ultrastructure of cells. Lead damaged the biological membranes after 2–3 days of exposure, causing the loss of cytoplasmic organelles and also injured the meristematic cell mitochondrial structure in roots (Jiang and Liung, 2010).

b) Effect of Pb on plant-water relationship

According to Sharma and Dubey, (2005) a reduced rate of transpiration was reported in the plants growing in lead- contaminated soils, for which various mechanisms have been suggested. The toxicity of lead induces growth retardation, resulting in decreased leaf area and causing low transpiration (Iqbal and Moshtaq., 1987). For examples, the reduced transpiration ratio in soybean (*Glycine max* (L.) Merr.), when exposed to Pb was correlated with a reduced leaf area resulting from leaf under growth (Elzbieta and Miroslawa, 2005). Plants subjected to lead treatments underwent altered water uptake leading to loss of turgor (Pinho and Ladeiro, 2012; Ruciñska-Sobkowiak et al., 2013). Lead exposure can also decrease the plasticity of cell walls, which causes plants to lose the turgor pressure of guard cells leading to the closure of stomata (Pinho and Ladeiro, 2012). Heavy metal ions such as lead tend to increase the concentrations of Abscisic acid (ABA) which also results in the closure of stomata. An altered rate of respiration and disarrayed oxidative phosphorylation found under the influence of lead can also disrupt the plant-water relationship (Sharma and Dubey, 2005).

c) Effect of Pb on nutrient uptake and assimilation

An imbalance is seen in the mineral nutrient content of plants if the concentration of lead increases in soil, which is one of the major reasons behind most of the toxic impacts of lead. Under Pb toxicity, significant changes in internal ratios of nutrients occur in plants (Kabata-Pendias and Pendias, 1992). There are two mechanisms by which lead decreases the uptake of micro and macronutrients. The first one is physical- it restricts the availability of major cations such as potassium, calcium, magnesium, manganese and iron to their absorption sites in the roots, (Godbold and Kettner, 1991). The other being chemical one, the metal interferes with cell metabolism, leading to changes in the activity of the membrane enzyme and the structure of the membrane, such as the sensitivity of K+-ATPase to Pb which induces potassium ion efflux from the cells. Apart from the cations, the uptake of anions is also affected. When exposed to polluted soil with lead, nitrate absorption decreases, with an associated decline in the activity of nitrate reductase and leading to an overall nitrogen metabolism imbalance. This reduced uptake is due to the moisture stress caused by lead (Burzynski and Gabrowski, 1984). In some plans such as *Pisum sativum*, enhanced nitrogen content was reported within the roots when the soil is treated with lead, probably due to inhibitory effect on nitrate reductase activity (Paivoke 2002).

d) Effect of Pb on photosynthesis

Plants exposed to lead ions report a decline in the rate of photosynthesis due to an alteration in the ultrastructure of chloroplast, restrained synthesis of chlorophyll, plastoquinone's and carotenoids, obstructed electron transport, inhibited activities of Calvin cycle enzyme as well as deficiency of carbon dioxide due to stomatal closure (Stefanov et al., 1995) .Lead toxicity causes oxidative stress on plants and alters chlorophyllase enzyme synthesis and function, resulting in a decreased photosynthesis rate due to chlorophyllase breakdown (Liu et al., 2008).

The photosynthetic behavior and structural changes in the photosynthetic apparatus of plants grown in lead contaminated soil were evaluated by Kosobrukhov et al., (2004). Compared to the control, stomatal conductance of lead-stressed plants was reported to decrease by 40-50 percent. The key reasons for decreased photosynthesis under Pb stress are a reduction in the leaf field, vascular bundles and total chlorophyll content, and decreased carbon dioxide influx due to stomatal closure (Romanowska et al., 2006).

The photosynthetic apparatus is also damaged because Pb has affinity for N- and S- ligands in the proteins (Ahmed and Tajmir-riahi, 1993). Degradation of chlorophyll also begins after treatment with lead, with chlorophyll b being more affected than chlorophyll a. The process is carried out in four steps: chlorophyllase, Mg-dechelatase, pheophorbide, oxygenase, and red chlorophyll catabolite reductase catalyzation (Harpaz et al., 2007).

Lead effects are observed for both donor and acceptor sites of PS I, PS II and cytochrome b/f complex. It is also established that inhibition by Pb affects PS II more than PS I (Rashid et al., 1994). In the entire plant, a decrease in photosynthesis is seen, which is thought to be due to stomatal closure rather than direct lead interference (Bazzaz et al., 1975).

e) Effect of Pb on respiration and ATP content

It is seen that respiration is equally affected by lead exposure of plants. Most of the studies carried out discuss the effect on leaves, with a little focus on roots. Lead affects the carboxylase activity of RuBisCO in C3 plants with a little effect on oxygenase activity, suggesting that photosynthesis is more affected than photorespiration, thus increasing the ratio of photosynthesis to photorespiration (Assche and Clijsters, 1990). Increased concentration of carbon dioxide was observed in leaves, due to decreased photosynthesis and increased respiration, which is probably due to mitochondrial respiration, while photorespiration being unaffected (Romanowska et al., 2002). The stimulation of respiration showed positive relation with increased production of ATP, which is probably needed to combat lead stress. Also, divalent cations like Pb, Cd can attach to mitochondrial membranes which can lead to decoupling of phosphorylation. Malate, succinate, and glycine substrates were more completely oxidized in mitochondria, separated from lead treated *P. sativum* leaves, than in mitochondria from control leaves (Romanowska et al., 2002). A three-times rise in the activity of NAD+ - malate dehydrogenase was seen in protoplasts of barley leaves treated with Pb when compared to protoplasts from control leaves (Romanowska et al., 2005). Jiang and Liu, (2010) reported vacuolization of endoplasmic reticulum and dictyosomes, mitochondrial swelling and loss of cristae during a 48-72 h lead exposure. At high concentrations, however, inhibition of respiration is observed.

f) Effect of Pb on oxidative metabolism

ROS (Reactive oxygen species) such as singlet oxygen, superoxide anion and hydrogen peroxide etc. are produced during the regular course of metabolism in aerobically respiring organisms. However, an excess amount of these can also harm the pigment systems and other respiring complexes in the cell.

One of the phytotoxic effects of Pb appears to be the initiation of oxidative stress in growing plants, owing to an increased production of ROS causing an unstable redox status of the cell (Sharma and Dubey, 2005). Lipid peroxidation caused due to Pb is reported to alter biological membranes (Gupta et al., 2009); eventually hampering the working of cellular organelles, such as peroxisomes, chloroplast and mitochondria (Malecka et al., 2008). When rice (*Oryza sativa* L.) seedlings were grown in sand culture containing500 and 1000 ìM lead nitrate in the medium, about 21 to 177% rise in the level of lipid peroxidases was observed during a growth period of 5-20 days, confirming that Pb induces oxidative stress in plants (Verma and Dubey, 2003). Lead-induced stress also lowers the plant protein pool which was primarily related with augmented oxidative damage (Brunet et al., 2009).

g) *Effect of Pb on mitosis and genotoxicity*

Patra et al., (2004) has reviewed studies on the impact of heavy metals, including Pb, on the plant's genetic system. Genotoxicity may not always be related to direct effects on mitosis by a change in nucleic acid content but rather an alteration in the proteins involved (Küpper, 2017). An early study of Weirzbicka (1994), reported that c-mitoses was one of the first genotoxic effects of lead which was later confirmed by authors who worked with different lead concentrations (Liu et al., 1994). Certain trends like aberrantly dividing cells (in prophase, metaphase, and anaphase), mitotic anomalies like chromosome bridges, c-mitosis, and chromosome stickiness can be detected (Küpper, 2017).

LEAD TOLERANCE IN PLANTS

Response of plants to Pb stress is in different ways, which depends upon the exposure conditions, concentration of the metal and the plant species. The two broader ways to cope with the stress are: the 'excluder' strategy, in which the concentration of Pb is sustained at an optimal low level, until an acute concentration of Pb is reached in the soil, after which the metal transports across the cell membrane. The other is the 'accumulator' strategy in which the metal gets accumulated inside the cell, hinting towards a specialized physiology (Baker, 1981).

Typha latifolia can colonize in both uncontaminated and metal polluted areas (Ye et al., 1997). It is able to maintain a low concentration of Pb in its leaves. This suggests that *T. latifolia* relies basically on the excluder strategy for avoiding Pb toxicity (Sharma and Dubey, 2005).

Plants try to acquire tolerance through prevention of translocation of lead, sequestering it in vacuoles and via antioxidant system (Doðru, 2020). Several nonspecific defense systems are also stimulated upon exposure to lead. These include production of osmolytes such as proline and polyamines such as putrescine, changes in the chemical composition of cell wall such as suberin deposition and fluctuations in the hormonal balance especially those of abscisic acid and ethylene (Seregin and Ivanov, 2001).

There are two other approaches to understand the Pb tolerance mechanisms in plants:

a) *Passive mechanisms*

These are generic responses shown by almost all plants in response to Pb. These include:

i. Immobilization of Pb in the rhizosphere.

ii. Callose deposition in the root cell walls, thus blocking the penetration of Pb (Krzes³owska et al., 2010).

iii. Pb localization in the cell wall by forming a complex with pectin carboxyl groups (Meyers et al., 2008).

iv. Exudation of metal precipitating compounds like oxalate.

b) *Inducible mechanisms*

These responses induce certain physiological modifications inside the cells upon exposure to Pb:

i. When the metal concentration inside the cells rises above a tolerable threshold, certain transporter proteins like divalent metal transporter 1 (DMT 1), expel metal ions into the extracellular space in plants (Meyers et al., 2008).

ii. Detoxification of Pb by cellular sequestration. The metal binds to organic compounds and then gets sequestered into different cell compartments: vacuoles (Meyers et al., 2008), endoplasmic reticulum vesicles or plasma tubules (Wierzbicka et al., 2007).

iii. Detoxification by production of antioxidants like cysteine and glutathione which quench the ROS induced by Pb stress. Lead treatment can induce different GSH genes, including glutathione synthetase, glutathione peroxidase, and glutathione reductase, and glutamyl cysteine synthetase. Glutathione also enhances accumulation of proline, which is associated with reducing the damage to membranes and proteins (Liu et al., 2009).

PHYTOREMEDIATION OF Pb CONTAMINATED SOILS

In contrast to the expensive engineering-based technologies and non-eco-friendly chemical approaches, the last century has witnessed the development of a more sustainable bioremediation methodology which aims at utilizing organisms such as plants, fungi and bacteria. The idea of phytoremediation or using plants for the remediation of heavy metals contaminated soils has received greater consideration in the recent years (Raskin et al., 1994; Vassil et al., 1998; Jarvis and Leung, 2002). It is a cost effective and a novel technology which uses plants for cleaning up a wider range of organic and inorganic toxicants (Shrirangasami et al., 2020). Phytoremediation is the use of plant-controlled interactions with groundwater and organic and inorganic molecules at contaminated sites to accomplish site-specific corrective goals (Landmeyer, 2011). It is the most sustainable and the least harmful way of remediation. Plants that grow in contaminated areas uptake and translocate toxic elements to the harvestable organs (Meagher, 2000). Phytoremediation can be achieved by employing a number of techniques such as, phytovolatilization, phytoextraction, Phyto stabilization, phytodegradation and rhizofiltration (Kamusoko and Jingura, 2017). The former two are the most preferred strategies. Phytoextraction uses plants to eradicate contaminants from the contaminated soils whereas in Phyto stabilization the intrinsic hazards posed by the contaminant are reduced without removing it from the site but rather by decreasing the bioavailability to the plants (Sharma and Dubey, 2005).

The concentration of Pb in roots is usually found to be higher than in the shoots possibly due to lower amounts of Pb translocation from root to shoot (Cunningham et al., 1995; Verma and Dubey, 2003). For these reasons, the most significant physiological factor for assessing the phytoextraction ability of plants is measuring the Pb quantities in the shoots (Huang and Cunningham, 1996). In a particular experimental analysis, it was found that certain cultivars of *Brassica juncea* shoots can accumulate up to 1.5% of Pb, when grown in nutrient solution containing 760 ìM Pb (Kumar et al., 1995).

Phytoremediation is mainly used to remediate metal contaminated soils in which hyperaccumulator plants are grown to uptake heavy metals in huge quantities. The hyperaccumulator plants store the heavy metals in above-ground portions such as shoots and leaves (Brennan and Shelley, 1999; Aliyu and Adamu, 2014).

PHYTOREMEDIATION OF Pb BY AROMATIC PLANTS

An important aspect for phytoremediation is the choice of plants that are to be used for the purpose. There are three basic aspects which needs to be considered; (i) high value of economic crop (ii) minimum use of risk in the end product and (iii) unfamiliar feature of the crop (*i.e.,* elevated biomass and elevated heavy metal extraction efficiency) (Pandey et al., 2009). The cultivation of aromatic plants for their direct and indirect uses is a common practice from early times. There are numerous aromatic plants which show the tolerance ability against the environmental contaminants and also extract them from the polluted sites (Jisha et al., 2017). Aromatic plants are not directly linked to a food chain. Certain aromatic plants can substantially accumulate heavy metals from polluted sites which are then removed after harvesting (Zheljazkov and Nielsen, 1996a; Zheljazkov and Warman, 2004). Moreover, studies have shown that aromatic plants like vetiver and lemongrass can endure toxic environments while simultaneously enhancing the quality of soil by reducing soil erosion (Chiang et al., 2006). Since one of the key aspects of using plants for the purpose of phytoremediation is the least risk in the end product consumption of the plant parts, aromatic plants provide a safer option and are much more eco-friendly as essential oils are the key end-product of aromatic crops, which are primarily used for non-edible purposes, such as in the production of detergents, soaps, cosmetics, perfumes, insect repellents, phytoremediation using aromatic plants can reduce food chain pollution (Lal et al., 2013). Evaluation of the risk associated with using aromatic crops for phytoremediation has been evaluated by many researchers (Pandey et al., 2019). The threat of heavy metal contamination in the essential volatile oils obtained from aromatic plants is stated to be the least (Scora and Chang, 1997; Zheljazkov and Nielsen, 1996b).

Furthermore, the demand and availability aspect plays a main role in favoring aromatic plants for phytoremediation. The last century has witnessed an increase in the demand of essential oils which are procured from aromatic plants (Verma et al., 2014). Thus, growing aromatic grasses and plants on polluted soils will not only help to restore the soil but also provide economic benefits.

PHYTOREMEDIATION CAPACITY OF SOME AROMATIC PLANTS FOR Pb CONTAMINATED SOILS

The most important physiological parameter for assessing the phytoextraction capacity of plants is measuring the Pb concentration in the shoots (Huang and Cunningham, 1996). Thus, higher the shoot/root concentration of Pb, higher is the capacity of the plant to move Pb and accumulate it (Sharma and Dubey, 2005). In another report by Reeves and Brooks, (1983) *Thlaspi rotundifolium* have been found to accumulate 130-8200 mg Pb/kg shoot dry weight. Table 1 summarizes the research that indicates the most effective aromatic plants for the phytoremediation of Pb from contaminated soils.

Cymbopogon citratus stem shows ability for the adsorption of Pb (II) ions from aqueous solution. Therefore, this plant can be used as effective, eco-friendly and low-cost adsorbent for the management of wastewater containing Pb (II) (Sobh et al., 2014). It was observed by Rotkittikhun et al., (2010) that the essential oil content in vetiver was actually enhanced by Pb. By planting vetiver grass in a lead mine zone, reclamation of Pb-contaminated soil can be achieved (Pandey et al., 2019). *Ocimum basilicum* can also act as a prospective Phyto stabilizer; but plants grown for phytoremediation purpose should be avoided for consumption in order to prevent food chain contamination (Pandey et al., 2019).

Thus, aromatic plants can not only act as excellent accumulators of heavy metals like Pb but can also help to remediate Pb contaminated soils by either being biosorbents or Phyto stabilizers.

CONCLUSION

Lead pollution due to anthropogenic activities has harnessed much attention from various plant specialists and environmentalists in the last century. Much of the potential sources of lead contamination are man-made. Lead from the soil can be taken up by plants and easily accumulated. This in turn leads to a continuous chain of passage of lead from plants to the consumers including humans. The lead is taken up by plants chiefly through leaves via air pollution followed by roots through soil. Once inside the plant, Pb can affect a multiple cascade of physiological and metabolic activities of plants such as seed germination and early plant establishment, maintaining turgor, uptake of nutrients, photosynthesis, respiration and ATP production. Moreover, it also exerts an oxidative stress and also has genotoxic effects on mitosis.

Plants have also evolved with the lead contamination and have developed various ways

Table 1: Phytoremediation capacity of various aromatic plants for Pb contaminated soils

Name of the plant species	Role in Pb phytoremediation	References
Cymbopogon citratus	Used as biosorbent for exclusion of Pb (III) from water solution upto 50%.	Hassan, 2016
Vetiveria zizaniodes	80-94% of Pb was removed from synthetic wastewater samples.	Singh et al., 2014
Pelargonium sps.	Reduced lead concentration in soil from 1400 ppm to 900 ppm.	Abdullah and Sarem, 2010
Ocimum basilicum	Phytostablisation of Pb	Prasad et al., 2010
Matricaria chamomilla	Pb excluder	Farzadfar et al., 2013
Salvia officinalis	Accumulate up to 61.8 mg/kg of Pb in the shoots.	Angelova, 2013
Mentha crispa	Concentration of Carovene, essential oil was increased up to 90% in presence of lead.	Sa et al., 2015

for detoxifying and tolerating the stress induced by lead. Most of the plants rely on the strategy of maintaining a low concentration of lead in their system while others which accumulate it develop some specialized physiology. Phytoremediation is the most sustainable and economical method for removing the heavy metals such as Pb from the soil. Aromatic plants are a great option for phytoremediation and reclamation of the affected soil, due to their low threat of toxification of end products, greater sustainability and least impact on the food channels among the organisms. These are evaluated chiefly on the basis of how much lead they can accumulate in their shoots. Various plants like vetiver, lemongrass, basil have been found efficient in this by various researchers either by working as accumulators, Phyto stabilizers or biosorbents.

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