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# Lead Toxicity and Tolerance in Plants

## Review Article

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**Abstract**

Lead (Pb) is the most common heavy metal contaminant in the environment. Plants absorb Pb from their environment, but it is not an essential element. Pb is quite common especially in the soil of roadside fields as a result of emission from the automotive exhaust. It is also found in fields with a long history of fertilization with fertilizers containing Pb as impurity. In fact, there are numerous sources of Pb including soil, water, air, batteries, toys, cans and fertilizers among others. Here in this review, we focus on the effects of Pb on plant growth and development and also discuss the mechanisms plants adopt to tolerate lead toxicity. Pb is among the most commonly present heavy metals in terrestrial and aquatic ecosystems. It enters these ecosystems through various natural and anthropogenic sources. Pb gets accumulated in a dose-dependent manner and causes toxicity to the plant. Due to uptake of Pb, the concentration of Mn is increased, while the total concentrations of most other minerals including K, Ca, Na, P, Mg, Zn, Fe, and Cu is reduced by Pb. The sprouting of young seedling and its development is limited by the plant exposure to Pb. Plants protect themselves against Pb toxicity through various mechanisms. There are at least three basic mechanism plants use to protect against Pb toxicity and they are passive mechanisms, inducible mechanisms and via antioxidant enzymes. Overall, we can conclude that Pb is harmful, but plants employ mechanisms to resist it. Thus further research should be to select and develop cultivars that have superior tolerance to Pb.

**Keywords:** Lead; Lead toxicity; Sources of lead; Tolerance; Uptake

## Introduction

A metal or metalloid that is hazardous to the environment, for example metals such as chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), silver (Ag), cadmium (Cd), antimony (Sb), mercury (Hg), thallium (TI) and lead (Pb) that are normally denser than iron are termed heavy metals [1].

Heavy metals naturally occur in the earth and are released during the weathering process. The concentrations of various heavy metals released during natural weathering are called background concentrations. However, human activities including disposal of industrial and domestic wastes, vehicular emissions, wastes from Pb acid batteries, paints and treated woods and the use of various organic and mineral fertilizers are the common sources of this heavy metal contamination [2]. During the 1930s-1970s, Pb was extensively used in gasoline as a component of tetra-ethyl lead [3]. In the aquatic environments of industrialized societies, it has been estimated that the Pb level increased two to three times those of pre- industrial level [4]. In North America, the use of leaded gasoline was largely phased out by 1996; however, soils in the fields in the vicinity of roads have high Pb concentration. From about 500 BC to 300 AD there was extensive use of lead in Roman aqueducts. As the lead azide or lead styphnate are used in firearms, there is accumulation of Pb in the firearms training grounds and such sites pose the risk of Pb poisoning of local population, especially the firing range employees [5].

There are several routes for heavy metals to end up in plants, animal and human tissues via air inhalation, contaminated diet and during manual handling. The major source of airborne contamination is via motor vehicle emission. It's not clear how the heavy metals are originated [6]. Heavy metal leaching from consumer and industrial wastes can pollute the water sources such as ground water, lakes, streams and rivers. Acid rain can exacerbate this process by releasing heavy metals trapped in soils [7]. Through the uptake of water laden with heavy metals, these metals enter the plants; and they find place in the animals when they feed on these contaminated plants; and the largest sources of heavy metals in humans is through the ingestion of plant and animal based foods. Another potential source of heavy metal contamination is the contact with skin, followed by its absorption through skin [8]. The heavy metals can accumulate in organisms as they are not metabolized [9].

The objective of this paper is to review the recent literature on the effects of Pb toxicity on plant growth and enzymatic activities. The salient results are discussed with examples from recent literature. Varietal differences in tolerance or resistance to Pb toxicity are also covered along with the need for future research to reduce Pb toxicity to crops.

## Sources of lead contamination in soil and water

Lead is harmful to human health as it is a toxic metal. The concentration of Pb, current medical condition, route of exposure (via air, water or food), and age of the person are the factors to consider for the degree of exposure and harmful effect. According to estimates, in children up to 20% of the total lead exposure can be attributed to a waterborne route. The main cause of Pb intake is via drinking of the Pb contaminated water. The young children, fetuses and infants are vulnerable to poisoning caused through Pb contaminated water

Lead processing and smelting plants work with both the primary and secondary Pb sources. Primary Pb is mined, after separation from ore, whereas, secondary Pb is recovered from used objects; such as used Pb- acid batteries; for reuse in other products. Smelting is a key process in production of Pb products, and involves the heating Pb ore or the recovered Pb with chemical reducing agents. Both primary and secondary smelting processes can be responsible for releasing large amounts of Pb into the surrounding environment.

There are different sources of Pb contamination in water resources as well as soil:

From home fittings made up of brass with Pb part of it, the delivery of water through water pipes made up of Pb or Cu pipes with Pb soldering, are the sources of Pb. In addition, the chances of Pb contamination of water are greater in recently built house (< 5years old) with the above-stated fittings, and when such pipes are used to carry naturally soft water and the water sits for several hours in these pipes.

The sources of Pb indeed are from numerous daily used common products in diverse locations, some of them quite unexpected. Some of the sources of Pb can be one never thought of; for example, selected toys, candies, and traditional medicines used in daily routine. Dust and chips from old paints are the most common sources leading at times to poisoning via food chain.

The salient results on Pb contamination through various sources are summarized in the following section:

**i. Soil:** Since 1973, a gradual phasing out of Pb in gasoline in the USA/India was started by the federal government, and the sale of leaded-gasoline was completely banned by 1996. However, Pb from car exhausts mixed with soil by roadside is still a source of Pb. The homes in the vicinity of busy streets likely have higher levels of Pb in the soil. Today, Pb still comes from metal smelting, battery manufacturing, and from industrial units that use Pb. The Pb emitted from these sources gets into the air and part of it settles down on the soil surface near homes, especially if the home is near one of these sources. Flaking Pb-based paint on the outside of buildings can also mix with the soil close to buildings. The soil contaminated by Pb-based paint can be a problem during home remodeling if the work is not carried out with proper precautions. However, once the soil is contaminated with Pb, wind can do the rest by stirring the contaminated dust and blowing it into homes and yards [10].

**ii. Drinking Water:** Pb seldom occurs naturally in water sources such as rivers and lakes. Pb enters drinking water primarily as a result of the corrosion or wearing of materials containing Pb in water distribution system in the households or via the plumbing work carried out in the buildings. These materials include Pb-based solder used to join copper pipes, brass and chrome plated brass faucets, and in some cases, pipes made of Pb used to connect houses and buildings to water mains. In 1986, the congress in USA banned the use of Pb solder containing greater than 0.2% Pb, and restricted the Pb content of faucets, pipes and other plumbing materials to 8.0%. Older construction may still have plumbings that have the potential to contribute Pb to drinking water [10].

**iii. Paint:** Pb has been used in paints to improve the ability of the paint to hide the surface it covers, add color and to make it more durable. The federal government in the USA for example, banned Pb paint for use in homes in 1978. Home, furniture and toys, which were made and painted before 1978 might contain Pb-based paints. When the chips of Pb-based paint turns into dust, or gets into the soil, then it becomes a point of concern.

**iv. Dust:** The most common way people are exposed to Pb is via Pb dust. There are many ways to generate Pb dust in homes like, Pb dust which mostly originates from flaking of the paint or when the paint is scraped, sanded, chipped and or disturbed during home remodeling. When young children put some items containing Pb dust on it into their mouths, they get exposed to Pb. Moreover, dust may be invisible to a naked eye.

**v. Air:** There may be Pb in outdoor and indoor air. Pb in outdoor air comes mainly from industrial sources (e.g., smelters, waste incinerators, utilities, and Pb-acid battery manufacturing). Wind-blown soil and road dust also might contain naturally occurring Pb as well as Pb from industrial sources, deteriorated paint and the combustion of leaded gasoline and aviation fuels leaded gasoline and aviation fuels. Sources of Pb in indoor air include outdoor air, suspended dust, and during the course of selected recreation or hobbies (e.g., making stained glass objects using Pb solder, shooting using Pb bullets at indoor firing ranges). Motor vehicle emissions are a major source of airborne contaminants including lead, nickel, cadmium, antimony, vanadium, zinc, palladium, cobalt, arsenic, platinum, and rhodium [6].

**vi. Folk medicines, Ayurvedic medicines and cosmetics:** Some of the folk medicines have Pb as contaminant. They often are used in the Southeast Asia, Middle East, India, the Dominican Republic, or Mexico. Regarding this issue there are two examples - Azarcon and Greta folk medicines. Azarcon is also known as Rueda, Maria Luisa, Coral and Alarcon and it is an orange powder where as Greta is present in yellow powder form. These medicines are used to treat the illness arising out of upset stomach. There is one more medicine called *Pay-loo-ah* which contains Pb, and is in red powder form. This medicine is used for the treatment of fever or rashes. There are some other folk medicines, which generally contain Pb including Golf, Bala (or BalaGoli), Ghasard, and Kandu. Some cosmetics such as Surma and Kohl (Alkohl) have also been reported to contain Pb .

In India or other eastern Asian countries, the traditional form of medicine practiced is Ayurveda. Ayurvedic medications may contain minerals, herbs, animal products or metals. These medicines may be non-standardized or standardized formulated. These Ayurvedic medicines are typically exported to the United States through both by followers and practitioners of Ayurvedic medicine.

**vii. Used Lead Acid Batteries:** Lead acid batteries are made of lead plates situated in a 'bath' of sulfuric acid within a plastic casing and rechargeable batteries. They can commonly be recognized as "car batteries" and are used in every country in world. The batteries can be charged many times, but after numerous cycles of recharging, lead plates eventually deteriorate causing the battery to lose its ability to hold stored energy for any period of time. Once the lead acid battery ceases to be effective, it is unusable and deemed a used lead acid battery (ULAB), which is classified as a hazardous waste under the Basel Convention.

## Symptoms and mechanism of lead toxicity to plants

Pb is among the most commonly present heavy metals in terrestrial and aquatic ecosystems. It enters these ecosystems through various natural and anthropogenic sources [11-13].

The Pb present in the soil solution is absorbed by the plant roots. A large proportion of $Pb^{2+}$ is retained in plant roots in precipitated form [14]. The accumulation of Pb in plants differs with plant species. The sprouting of seedlings and development is limited by the plant exposure to Pb exposure [15-17]. The growth of aerial part of plants and roots are inhibited by the low concentration of Pb [18,19]. If the Pb content is higher in the growing medium, the inhibition is strongly seen on root growth [12]. The stubby, short, bent and swollen roots with an increase number of secondary roots per unit root length are seen due to Pb toxicity [18]. The accumulation of Pb results in reduced growth and lower uptake of various minerals by plants. The concentration and total amount of the most of the minerals (Na, K, Ca, P, Mg, Fe, Cu and Zn) are reduced, although an increase in Mn concentration is seen as Mn uptake is less reduced relative to the growth of the whole plant. A stronger decrease in the proline and chlorophyll a and b is seen due to the deficiency of mineral nutrients. It has also been observed that Pb reduces soluble proteins in wheat plants at a range of concentrations; and Pb accumulation increases with the increase in the exogenous Pb level. Moreover, Pb leads to a broad range of biochemical and physiological dysfunctions including seed germination, nitrate assimilation, water status and the growth [13,20,21]. However, there are some limitations in the transportation of Pb from root to shoot [22]. Pb also adversely affects carbon dioxide assimilation, photosynthetic rate, carotenoid contents and chlorophyll, and these processes strongly reduced so much so that the exposure of plants greatly reduces the photosynthetic rate [23]. Following Pb exposure of plants, there was a decrease in Ca, Fe and Zn levels in the root tips [24]. The inhibition of mineral ion uptake appears to be a general consequence of Pb exposure. Conversely, an increased provision of certain inorganic salts can indeed antagonize Pb effects to some extent [25]. The generation of free radicals such as superoxide anion radical ($O^{2-}$), hydrogen peroxide ($H_2O_2$), singlet oxygen, and hydroxyl radical (HO•), which cause oxidative stress to plants and reactive oxygen species (ROS) are the important features of Pb toxicity to plants [26]. Following 48-72 h of Pb exposure, the loss of cristae, mitochondrial swelling, vacuolization of endoplasmic reticulum, injured plasma membrane and dictyosomes and deep colored nuclei have been reported [27]. Lead interacts with the proteins present in cytoplasm and higher concentration of Pb may decrease the protein pool [28-31]. Due to the modification in gene expression, increased ribonuclease activity [17], acute oxidative stress of reactive oxygen species (ROS) [31-33], protein utilization by plants for the purposes of Pb detoxification and diminution of free amino acid content [32] that is correlated with a disturbance in nitrogen metabolism [28] the quantitative decrease in total protein is seen with Pb addition. However, certain amino acids, like proline increase under Pb stress [34]. Such proteins play a major role in Pb tolerance by the plant. In contrast, low concentrations of Pb increase total protein content [29].

## Mechanisms of Lead Tolerance

There are various ways by which plants respond to the noxious effects of Pb. For example, via uptake of selective metal, metal binding to the root surface, and induction of antioxidants like proline, non-protein thiol (NP-SH), glutathione, cysteine, ascorbic acid, and antioxidant enzymes, such as guaiacol peroxidase (GPX), superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), and glutathione reductase (GR) [33].

**i. Passive Mechanisms:** Pb interacts with cellular components and even a small amount of Pb increases the cell wall thickness. Plant cell walls contain pectin; and the complexation of Pb with the carboxyl groups of pectin is regarded as the most important interaction by which plant cells can resist Pb toxicity [25]. It was observed in *Funaria hygrometrica* protonemata that binding of Pb to JIM5-P acted as a physical barrier, and restricted the access Pb to the plasma membrane. However, in later studies it was reported that the Pb bound to JIM5-P within the cell can be taken up or remobilized by endocytosis, together with pectin epitope [35].

**ii. Inducible Mechanisms:** Recently, it has been reported by several authors that when the transporter proteins are present among plant cells, they play an important role in metal detoxification as they allow the metal ion excretion into extracellular spaces [36- 38]. The human divalent metal transporter 1 (DMT1) expressed in yeast has been shown to transport Pb via a pH-dependent process [39] in plants. Simultaneously, several ATP-binding cassette (ABC) carriers such as AtATM3 or AtADPR12 at ATP-binding sites in *Arabidopsis* were reported to be involved in resistance to Pb [40, 41]. Although, suspected to act against Pb, this detoxification mechanism has not yet been clearly established. Transcriptome analysis has shown that the gene expression of these carriers is stimulated by Pb [11].

**iii. Antioxidant Enzymes:** To avoid oxidative damage and for achieving the increased production of ROS, all plants have an antioxidant enzymes system. This system scavenges the ROS, which are present in different cell compartments [32]. The synthesis of these active enzymes may be induced or inhibited by Pb-induced toxicity.

However, Pb-induced induction or inhibition of antioxidant enzymes depends on plant species, specific form of the metal, and the duration/intensity of the treatment [19,32]. Generally, the plant enzymatic activities are inhibited by Pb, and this is followed by change in the values of the inactivation constant (*K*i) range between $10^{-5}$ and $2 \times 10^{-4}$ M, which means 50% inhibition in enzymatic activities in this concentration range [21].

## Conclusions

Pb is really a harmful metal for crops and is present everywhere. From the soil, air, water and food materials, it contaminates the complete ecosystem. There are many mechanisms by which plants resist or tolerate Pb. Thus it is possible to select those cultivars that show higher tolerance to Pb. We can also employ biotechnological tools to develop cultivars that resist Pb toxicity by identifying gene (s) responsible.

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