

The effect of lead on plants in terms of growing and biochemical parameters: a review

Abstract

Contamination of soil and water by various heavy metals such as lead, silver and cadmium is increasing day by day as result of different activities, such as industrialization and urbanization. Lead (Pb) is an example of potential heavy metal that is neither essential element nor have any role in the process of cell metabolism but is easily absorbed and accumulated in different parts of a plant. The lead uptake is mainly regulated by PH, particle size, and cation exchange capacity of the soil, root exudation and by different other physical and chemical parameters. The high concentration of the heavy metals such as lead can cause a number of toxic symptoms in plants that may be retardation in growth (Stunted growth), negative effects on photosynthesis (chlorosis), blackening of roots and different other symptoms. Lead has the ability to inhibit photosynthesis, disturb mineral nutrition and water balance, changes hormonal status and affects membrane structure and permeability. The paper reviewed the effects of lead ion on the growth and some biochemical parameters in plants.

Keywords: lead, plant, growth, biochemical parameters

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Introduction

The unrestricted developmental activities such as industrialization and urbanization carried out during the past few years have given rise to serious problems of environmental contamination. A general increase in the level of heavy metals poses a pervasive threat to the natural ecosystem. Heavy metals are defined as metals having a density higher than 5 g/cm³. Of the total 90 naturally occurring elements, 53 are considered heavy metals and few are of biological importance.¹ Based on their solubility under physiological conditions, 17 heavy metals may be available to living cells and have significance for the plant and animal communities within various ecosystems.² Increase in levels of heavy metals in soils could also be attributed to factors such as soil properties or different agricultural practices such as application of sludge to agricultural land.³ Among the heavy metals Zinc (Zn), Nickel (Ni), Copper (Cu), Vanadium (V), Cobalt (Co) and Chromium (Cr) are non-toxic heavy elements at low concentration. Arsenic (As), Mercury (Hg), Silver (Ag), Cadmium (Cd), Lead (Pb) and Aluminium (Al) have no known function as nutrients and seems to be more or less toxic to plants and microorganisms.⁴ Accumulation of heavy metals such as cadmium in the environment is now becoming a major cause of environmental pollution.

The toxicity produced by transition metals generally involves Neurotoxicity, Hepatotoxicity and Nephrotoxicity.⁵ Differences in solubility, absorbability, transport and chemical reactivity in these metals will lead to specific differences in toxicity within the body. The chemical form of heavy metals in soil solution is dependant of the metal concerned, pH and the presence of other ions.⁶ The toxicity symptoms observed in plants in the presence of excessive amounts of heavy metals may be due to a range of interactions at the cellular level.⁷ Toxicity may result from the binding of metals to sulphhydryl groups in proteins, leading to an inhibition of activity or disruption of structure.⁸ Enzymes are one of the main targets of heavy metal ions and prolonged exposure of soils to heavy metal results in marked

decreases in soil enzymes activities. In addition, heavy metals excesses may stimulate the formation of free radicals and Reactive Oxygen Species.⁹

Lead

Lead is the most important toxic heavy element in the environment. Due to its important physico-chemical properties, its use can be retraced to historical times. Globally, it is an abundantly distributed, important yet dangerous environmental chemical.¹⁰ Its important properties such as softness, malleability, ductility, poor conductivity and resistance to corrosion seem to make difficult to give up its use. Due to its non-biodegradable nature and continuous use, its concentration accumulates in the environment with increasing hazards.

Sources of lead

Human exposure to lead and its compounds occurs mostly in lead related occupations with various sources like leaded gasoline, industrial processes such as smelting of lead and its combustion, pottery, boat building, lead based painting, lead containing pipes, battery recycling, grids, arm industry, pigments, printing of books, etc. Though its widespread use has discontinued in many countries of the world, it is still used in many industries like car repair, battery manufacturing and recycling, refining, smelting, etc. Traditional medicines were also found to contain heavy metals including lead. A number of diseases have been reported due to consumption of traditional medicine.¹¹ Ayurvedic medicines are considered to be heavily contaminated with heavy metals. In one recent study, the blood lead levels were evaluated in consumers of ayurvedic medicines. Of the 115 participants 40% were found to have an elevated blood lead levels of 10µg/dL. Lead toxicity may be caused through fruits and vegetables contaminated with high lead levels from the soils where they were grown.

Results and discussion

Adverse effects of lead

The visual general symptoms of lead toxicity are fast inhibition of root growth, underdeveloped growth of the plant, blackening of root system and chlorosis. Lead inhibits photosynthesis, let downs mineral nutrition, water balance and enzyme activities.¹² These disorders upset normal physiological activities of the plant. At high concentrations lead may finally result to cell death.¹³ Similarly, lead inhibits germination of seeds and retards growth of seedlings, decreases germination percent, germination index, root/shoot length, tolerance index and dry mass of roots and shoots.¹⁴ The growth development, fresh biomass and growth tolerance index of root, shoot and leaves were negatively affected by increasing levels of lead concentrations in tomato seedlings. Similar results were obtained by some other studies at the calculated lead concentrations: root, shoot and leaf growth; fresh and dry biomass is greatly reduced in *Pisum Sativum*, in *Zea mays*.¹⁵ Extreme concentration of lead causes dangerous effects to plants; it also results in phytotoxicity of cell membrane. Possible unexpected mechanisms include changes in permeability of cell membrane, reaction of sulphhydryl (-SH) groups with cations, possible attraction for reacting with phosphate groups and active groups of ADP and ATP.¹⁶ Effects of lead have been reported on flower production, plants produce less number of flowers in high concentration of lead.¹⁷ Study on soybean have indicated that the lead toxicity induced a histological change in leaves, and made a thin leaf blade, minified the xylem and phloem in the vascular bundles, and also reduced the diameter of the xylem vessels.¹⁸ Same pathological changes in ultra structure level were testified on other plant species by Patel et al.¹⁹ & Wozny et al.²⁰ At the same time, all these damage could disrupt many plant activities including ant oxidative system, photosynthesis, respiration, mineral nutrition, membrane structure and properties and gene expression.²¹

Earlier studies confirmed that the damage to plant root system and the decrease in transpiration strength has caused by excess of lead.²² and brought about a reduction in water uptake, then inadequate supply of water to the above ground plant parts. Lead causes disorder in the composition of both the lipid membrane and the protein fraction, enabling its permeation into cells.²² The growth-development, fresh-dry biomass and growth tolerance index of root, shoot and leaves were negatively altered by increasing lead concentrations in tomato seedlings. Same results were obtained by some other studies at the calculated lead concentration: root, shoot and leaf growth, fresh and dry biomass were critically reduced in *Pisum Sativum*,²³ *Zeamays*,¹⁵ *Paspalum distichum* and *Cynodondactylon*,²⁴ in *Lycopersicon esculentum*,²⁵ *Ipomoea aquatic*,²⁶ *Phaseolus vulgaris* and *Lens culinaris*.²⁷ Lead can also alter the activity and quantity of the key enzyme of various metabolic pathways such as those of the photosynthetic Calvin cycle,²⁸ nitrogen metabolism,²⁹ and sugar metabolism.³⁰ Leaves are considered as one of the most important plant organs because of their role in capturing light and making food by the process of photosynthesis. In seeds, the testa avoids entry of lead into the internal tissues until it is ruptured by the developing radicle. Once the testa is ruptured, lead is taken up very rapidly, with distinguished exceptions occurring in the meristematic regions of the radicle and hypocotyls. In cotyledons, lead moves through the vascular tissues and tends to accumulate in discrete areas in the distal parts.³¹

Effects of lead on biochemical properties of plants

Like different heavy metals, lead treatment also affects the

activity of a wide range of enzymes of different metabolic pathways. Chloramphenicol acetyl tranferase (CAT) is oxidoreductase that decomposes H₂O₂ to water and molecular oxygen, and it is one of the important enzymes involved in the removal of toxic peroxides. CAT activities in cuttings and seedlings significantly increased at lower lead concentrations, while at higher lead concentrations, it decreased. Reduced CAT activity at higher concentration of lead might be attributed to inactivation of enzyme by ROS, decrease in synthesis of enzyme, or change in assembly of its subunits.³⁰ In most the inhibition exerted by lead on enzyme activity results from the interaction of lead with enzyme -SH groups.³² The vital enzyme of chlorophyll biosynthesis, α -amino laevulinate dehydrogenase, is powerfully inhibited by lead ions.³³ Lead also inhibits the activities of enzymes of the reductive pentose phosphate pathway.³⁴ In leaf homogenates of spinach the activity of ribulose-bis-phosphate carboxylase/oxygenase was inhibited even at a lead nitrate concentration of 5 μ M. Lead was found to be highly definite in inhibiting ATP synthetase/ATPase.³⁵ *In vitro* application of lead to mitochondrial preparations from plant cells exposed a decrease in respiration rate with increasing lead concentrations.³⁶ Using isolated chloroplasts and mitochondria in different plant species it has been shown that lead affects the flow of electrons via the electron transport system.³⁷ The inhibitory effect of lead at higher concentrations appears to be due to disconnection of oxidative phosphorylation.³⁸ At lower concentrations, however, a stimulation of respiration is observed in whole plants, detached leaves, isolated protoplasts and mitochondria.³⁹ At higher concentrations of lead, inhibition of respiration is observed. Respiration of corn root tips decreased by 10-17 % after 1 hour treatment with 20 mM Pb and by 28-40 % after 3 hours treatment.⁴⁰ Lead is regarded as one of the most potent metal ions for the inhibition of chloroplastic ATP synthetase/ATPase activity and for the destruction of the membranes.³⁵ Although the sensitivity of photophosphorylation to heavy metal ions is well documented, there is no general agreement regarding their site neither of action nor on the underlying mechanism.

Effect of lead on photosynthesis

The process of photosynthesis is unfavorably affected by lead toxicity. Plants exposed to lead ions show a decline in photosynthetic rate which results from partial chloroplast ultra-structure, restrained synthesis of chlorophyll, plastoquinone and carotenoids, obstructed electron transport, inhibited activities of Calvin cycle enzymes, as well as deficiency of CO₂ as a result of stomatal closure.⁴¹ *Ceratophyllum demersum* plants when grown in aquatic medium containing Pb(NO₃)₂ showed distinct changes in chloroplast fine structure.⁴² Leaf cells of such plants showed a reduction in grana stacks together with a reduction in the amount of stroma in relation to the lamellar system as well as absence of starch grains. Lead treatment also changes the lipid composition of thylakoid membranes.⁴¹ Lead inhibits chlorophyll synthesis by causing reduced uptake of essential elements such as Magnesium and Iron by plants. It harms the photosynthetic apparatus due to its affinity for protein N- and S-ligands.⁴³ An enhancement of chlorophyll degradation occurs in lead-treated plants due to increased chlorophyllase activity.⁴⁴ Chlorophyll b is reported to be more affected than chlorophyll a by lead treatment.⁴⁵ Lead effects have been described for both donor and acceptor sites of photosynthesis-2 (PS II), the cytochrome b/f complex and photosynthesis-1 (PS I). It is largely accepted that PS I electron transport is less sensitive to inhibition by lead than photosynthesis-2 (PS II).⁴⁶

Effects on Germination and Growth

When plants are exposed to lead, even at micromolar levels, adverse effects on germination and growth can occur.⁴⁷ Germination is strongly inhibited by very low concentrations of Pb²⁺.⁴⁸ Lead-induced inhibition of seed germination has been reported in *Hordeum vulgare*, *Elsholtzia argyi*, *Spartina alterniflora*, *Pinus halepensis*, *Oryza sativa*, and *Zea mays*.⁴⁸ At higher concentrations, lead may speed up germination and simultaneously induce adverse effects on the length of radical and hypocotyl in *E. argyi*.⁴⁸ Inhibition of germination may result from the interference of lead with protease and amylase enzymes.⁴⁹ Lead exposure in plants also strongly limits the development and sprouting of seedlings. At low concentrations, lead inhibits the growth of roots and aerial plant parts.⁴⁸ This inhibition is stronger for the root, which may be correlated to its higher lead content.⁵⁰ Lead toxicity may also cause swollen, bent, short and stubby roots that show an increased number of secondary roots per unit root length.⁴⁷ Recently, Jiang et al.⁵¹ reported mitochondrial swelling, loss of cristae, vacuolization of endoplasmic reticulum and dictyosomes, injured plasma membrane and deep colored nuclei, after 48–72 hours of lead exposure to *A. sativum* roots. Arias et al.⁵² reported significantly inhibited root elongation in Mesquite (*Prosopis* sp.). Plant biomass can also be restricted by high doses of lead exposure.⁵³ Under severe lead toxicity stress, plants displayed obvious symptoms of growth inhibition, with fewer, smaller, and more brittle leaves having dark purplish abaxial surfaces.⁴⁸

Conclusion

In conclusion, lead is non essential element for plant although, it accumulates in different parts of plant and negatively affects various physiological processes. Such physiological processes include photosynthesis, respiration, mineral nutrition, membrane structure and properties and gene expression. Lead accumulation in the soil inhibits germination of seeds and retards growth of seedlings, decreases germination percent, germination index, root/shoot length, tolerance index and dry mass of roots and shoots. Therefore, this is the responsibility of Government and various environmental agencies to controlling heavy metals pollution especially lead.

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Conflict of interest

The author declares that no conflict of interest exists.

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