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A Mini Review on Lead (Pb) Toxicity in Plants

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Abstract

Contamination of soil by various heavy metals is increasing day by day by different activities, such as industrialization and urbanization. Lead (Pb) is one of the potential heavy metal that is neither essential element nor has any role in the process of cell metabolism but it is easily absorbed and accumulated in different parts of a plant. The Pb 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 Pb can cause a number of toxic symptoms in plants that may be retardation in growth (Stunted growth), negative affect on photosynthesis (chlorosis), blackening of roots and different other symptoms. Lead (Pb) has the ability to inhibit photosynthesis, disturb mineral nutrition and water balance, changes hormonal status and affects membrane structure and permeability. This review describes different morphological, physiological and biochemical effects of Lead (Pb) toxicity in plants.

Key words: Cation, Chlorosis, Lead, PH

1. Introduction

Lead (Pb) is a heavy metal (Chaney and Ryan, 1994) and also called protoplasmic poison (Johnson and Eaton, 1980). Lead is a strong environmental pollutant and is toxic even in very low concentration (Levine *et al* 1989). It is not essential for plant and accumulated in different parts of the plant (Sharma and Dubey, 2005).

2. Sources of Pb

Main sources of Pb are exhaust fumes of automobiles, chimneys of factories using Pb, effluent from the storage battery, industry, mining and smelting, Pb ores, metal plating and finishing operations, fertilizers, pesticides, additives in pigments and gasoline (Elick *et al.*, 1999). In developing countries like Pakistan Pb paints, Pb water pipes, Pb acid batteries, Pb containing eye cosmetics, Pb food cans, Pb in petroleum as anti-knocking agent and Pb oaring and mining are constant sources of Pb intoxication in general population (Farooq *et al*., 2008). In a long term field experiment (41 years) relating regular application of mineral fertilizers to crops of sunflower or barely charted by oat winter rye rotation, showed that the fertilizers increased the level of mobile forms of Pb in the soil and also its uptake by the crops (Stefanov *et al*., 1995). Pb is available to plants from soil and aerosol sources. Pb uptake studies in plants have demonstrated that roots have the ability to take up huge quantities of Pb whilst simultaneously greatly restricting its translocation to above ground parts (Lane and Martin, 1977). This declaration was overturned by Miller and Koeppe, 1971 who stated that *Zea Mays* L. plants could accumulate and translocate great quantities of Pb in the leaves in a concentration dependent manner. Different sources of Pb are summarized by Sahrma and Dubey, 2005 in Figure 1. Pb compounds are major pollutants emitted by automobiles, as it is evident that those plants which are growing near highways are usually exposed to more Pb than other locations (Paivoke, 2002) and are thus more affected. Pb affected soils contain Pb in the range of 400-800 mg/kg soil (Angelon and Bini, 1992). The Pb which is accumulated in the streets and highways is transported to surface streams by rain water and consequently pollutes other surface waterways and soil. Mine water also transports a huge amount of fine grained sediments contaminated with Pb (Laxen and Harrison, 1977).

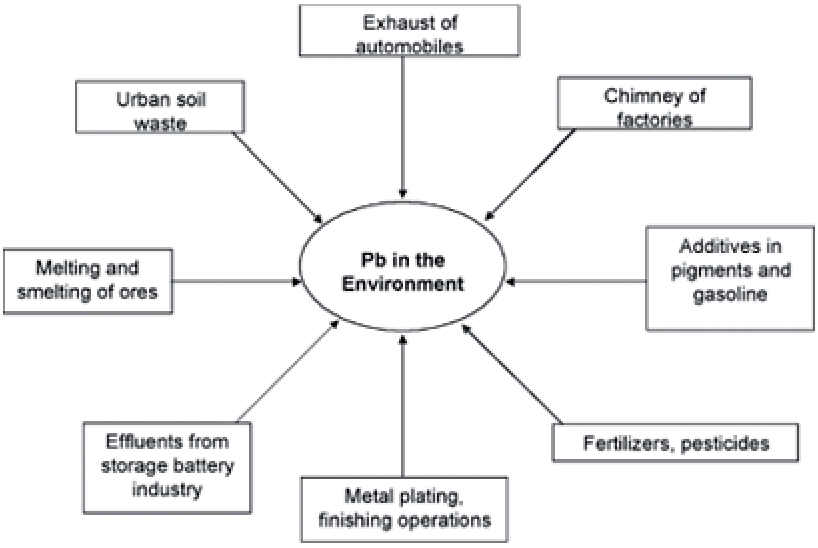

Figure 1. Sources of lead pollution in the environment.

3. Adverse Effects of Lead

The visual general symptoms of Pb toxicity are fast inhibition of root growth, underdeveloped growth of the plant, blackening of root system and chlorosis. Pb inhibits photosynthesis, let downs mineral nutrition and water balance, enzyme activities, (Burton *et al.*, 1984; Sharma and Dubey, 2005). These disorders upset normal physiological activities of the plant. At high concentrations Pb finally may lead to cell death (Ernst, 1998; Seregin and Ivanov, 2001). Similarly, Pb 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 (Mishra and Choudhari, 1998). The growth development, fresh biomass and growth tolerance index of root, shoot and leaves were negatively affected by increasing levels of Pb concentrations in tomato seedlings. Similar results were obtained by some other studies at the calculated Pb concentrations: root, shoot and leaf growth; fresh and dry biomass is greatly reduced in *Pisum Sativum* (Kevresan *et al.*, 2001), in *Zea mays (*Malkowski *et al.*, 2002; Cimrin *et al.*, 2007). Extreme concentration of Pb 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 sulphydryl (-SH) groups with cations, possible attraction for reacting with phosphate groups and active groups of ADP and ATP (William, 1976). Effect of Pb has been reported on flower production, plants produce less number of flowers in high concentration of Pb (Opeolu *et al.*, 2010). Study on soybean have indicated that the Pb 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 (Elzbieta and Chwil, 2005). Same pathological changes in ultrastructure level were testified on other plant species by Patel and Devi, 1986 and Wozny *et al.*, 1991. 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 (Bittell *et al.*, 1974; Bazzaz *et al.*,1975; Burzynski, 1985;

Jones and Harwood, 1993; Kastori *et al*., 1992; Jones *et al.*, 1987; Maksymiec, 1997; Rama and Prasad, 1999; Smith *et al*., 1985; Taylor, 1995). Earlier studies confirmed that the damage to plant root system and the decrease in transpiration strength has caused by excess of Pb (Kastori *et al*., 1992) and brought about a reduction in water uptake, then inadequate supply of water to the above ground plant parts. Pb causes disorder in the composition of both the lipid membrane and the protein fraction, enabling its permeation into cells (Kastori *et al*., 1992). The growth-development, fresh-dry biomass and growth tolerance index of root, shoot and leafs were negatively altered by increasing Pb concentrations in tomato seedlings. Same results were obtained by some other studies at the calculated Pb concentration: root, shoot and leaf growth, fresh and dry biomass were critically reduced in *Pisum sativum* (Kevresan *et al*., 2001), *Zeamays* (Małkowski *et al*., 2002; Çimrin *et al*., 2007), *Paspalumdistichum* and *Cynodondactylon* (Shua *et al*., 2002), in *Lycopersicon esculentum* (Jaja and Odoemena, 2004), *Ipomoea aquatica* (Gothberg *et al.*, 2004), *Phaseolus vulgaris* and *Lens culinaris* (Haider *et al*., 2006). Pb can also alter the activity and quantity of the key enzyme of various metabolic pathways such as those of the photosynthetic Calvin cycle (Stevens *et al.* 1997), nitrogen metabolism (Kumar and Dubey 1999), and sugar metabolism (Verma and Dubey 2003). 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 Pb into the internal tissues until it is ruptured by the developing radicle. Once the testa is ruptured, Pb is taken up very rapidly, with distinguished exceptions occurring in the meristematic regions of the radicle and hypocotyls (Lane and Martin, 1977). In cotyledons, Pb moves through the vascular tissues and tends to accumulate in discrete areas in the distal parts (Lane and Martin, 1977). The various adverse effects of Pb in plants are summarized in Figure 2 by Sharma and Dubey, 2005.

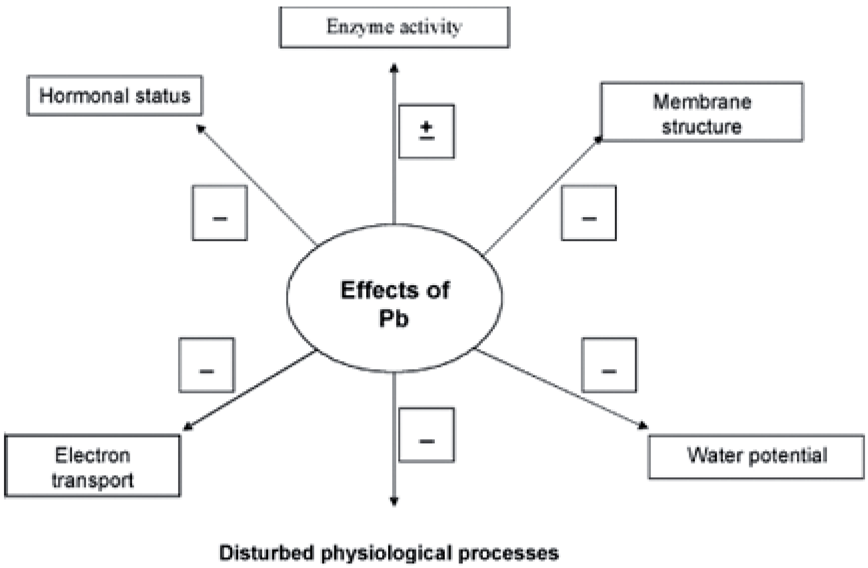

Figure 2. A generalized view of lead toxicity in plants. Pb phytotoxicity involves decreased water potential, alteration in membrane permeability, decrease in hormonal status and electron transport activities, whereas activities of enzymes are either increased or inhibited. These events ultimately result in overall disturbed physiological processes. '+' and '–' signs indicate positive and negative effects respectively.

4. Effects of Pb on Respiration, ATP Content, Protein Contents and Antioxidant Enzyme Activities

Like different heavy metals, Pb treatment also affects the activity of a wide range of enzymes of different metabolic pathways. Chloramphenicol acetyl tranferase (CAT) is oxidoreductase that decomposes H_2O_2 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 Pb concentrations, while at higher Pb concentrations, it was decreased. Reduced CAT activity at higher concentration of Pb might be credited to inactivation of enzyme by ROS, decrease in synthesis of enzyme, or change in assembly of its subunits (Verma and Dubey 2003). In most the inhibition exerted by Pb on enzyme activity results from the interaction of Pb with enzyme –SH groups (Levina, 1972). The vital enzyme of chlorophyll biosynthesis, α-amino laevulinate dehydrogenase, is powerfully inhibited by Pb ions (Prassad, 1996). Pb also inhibits the activities of enzymes of the reductive pentose phosphate pathway (Hampp *et al.*, 1973). In leaf homogenates of spinach the activity of ribulose-bis-phosphate carboxylase/oxygenase was inhibited even at a Pb nitrate concentration of 5 μM (Vallee and Ulmer, 1972). Pb was found to be highly definite in inhibiting ATP synthetase/ATPase (Tu Shu and Brouillette, 1987). In vitro application of Pb to mitochondrial preparations from plant cells exposed a decrease in respiration rate with increasing Pb concentrations (Reese and Roberts, 1985). Using isolated chloroplasts and mitochondria in different plant species it has been shown that Pb affects the flow of electrons via the electron transport system (Miles et al., 1972; Bazzaz *et al.*, 1975). The inhibitory effect of Pb at higher concentrations appears to be due to disconnection of oxidative phosphorylation (Miller *et al.*, 1973). At lower concentrations, however, a stimulation of respiration is observed in whole plants (Lee *et al.*, 1998), detached leaves (Lamoreaux and Chaney, 1978), isolated protoplasts (Parys *et al.*, 1998) and mitochondria (Koeppe, 1977). At higher concentrations of Pb, inhibition of respiration is observed. Respiration of corn root tips decreased by 10-17 % after 1 h treatment with 20 mM Pb and by 28-40 % after 3 h treatment (Koeppe, 1977). Pb 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 (Tu Shu and Brouillette, 1987). Although the sensitivity of photophosphorylation to heavy metal ions is well documented, there is no general agreement regarding their site of action nor on the underlying mechanism.

5. Effect of Pb on Photosynthesis

The process of photosynthesis is unfavourably affected by Pb toxicity. Plants exposed to Pb ions show a decline in photosynthetic rate which results from partial chloroplast ultrastructure, restrained synthesis of chlorophyll, plastoquinone and carotenoids, obstructed electron transport, inhibited activities of Calvin cycle enzymes, as well as deficiency of CO_2 as a result of stomatal closure (Stefanov *et al.*, 1995). *Ceratophyllum demersum* plants when grown in aquatic medium containing $Pb(NO_3)_2$ showed distinct changes in chloroplast fine structure (Rebechini and Hanzely, 1974). 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. Pb treatment also changes the lipid composition of thylakoid membranes (Stefanov *et al.*, 1995). Pb inhibits chlorophyll synthesis by causing reduced uptake of essential elements such as Mg and Fe by plants (Burzynski, 1987). It harms the photosynthetic apparatus due to its affinity for protein N- and S- ligands (Ahmed and Tajmir-Riahi, 1993). An enhancement of chlorophyll degradation occurs in Pb-treated plants due to increased chlorophyllase activity (Drazkiewicz, 1994). Chlorophyll b is reported to be more affected than chlorophyll a by Pb treatment (Vodnik *et al.*, 1999). Pb 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 Pb than photosynthesis-2 (PS II) (Mohanty *et al.*, 1989; Sersen *et al.*,1998).

6. Conclusion

In summary, lead is not an essential element for plant although, it accumulates in different parts of plant and negatively affects various physiological processes. Even in high concentrations it completely kills the plant. Therefore, this is the responsibility of Government and various environmental control agencies to promote crop yield by controlling lead pollution.

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