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Concept of Metal Hyperaccumulation in Plants

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Abstract:

The swift growth of chemical industries over the past few decades has resulted in contamination of the environment due to toxic waste contaminants. In order to maintain good quality of soils and waters and keep them free from contamination, continuous efforts have been made to develop technologies that are easy to use, sustainable and economically feasible. The use of plant species for cleaning polluted soils and waters named as phytoremediation has gained increasing attention since last decade, as an emerging cheaper technology. Certain Plant species have the property to resist moderately high concentration of metals without showing toxic effects. Metal accumulators are usually referred to as Hyperaccumulators that concentrate or uptake metals in their different tissues to an intensity far greater than those present in the soil or in non-accumulating species growing nearby. Hyperaccumulators plants species can actively accumulate or concentrate massive quantity of one or more heavy metals/pollutants from the surroundings. Antioxidant enzymes form a part of the battery of stress mitigation repertoire in hyperaccumulators plants species against metal excess. This review provides a brief outline of metal hyperaccumulation in plants along with information about different types of hyperaccumulator plant species and reveals information regarding stress tolerance in such plant species.

Keywords: *Metal toxicity, Metal accumulation, Hyperaccumulation, Metal tolerance and Thlaspi caerulescens*

Introduction:

The environmental pollution with heavy metals is a global problem that has resulted from anthropogenic activities. In nature land and water are precious natural resources for the sustainability of agriculture and the civilization of mankind. However, rapid industrialization and urbanization shows maximum exploitation and severe pollution in these resources. Each source of contamination has its own damaging effects to plants, animals and ultimately to human health, but those that add heavy metals to soils and waters are of serious concern due to their persistence in the environment and carcinogenicity to human beings. Heavy metals are recognized as one of the major environmental pollutants due to their persistence in the environment and produces toxic effects in living organisms. They cannot be destroyed biologically but cab be transformed from composite to another form and cause different health problems (Ali et al. 2013; Memon and Schröder, 2009). They have the tendency to bioaccumulates in tissues of animals possess great menace to both human health and natural environment (Khan et al. 2010).Therefore, alternative cost effective clean up techniques are long sought after. Phytoremediation is one such cost effective, novel plant-based remediation technology that can be applied to clean up inorganic and organic contaminated soils, water and sediments. Certain Plant species have the property to resist moderately high concentration of metals without showing toxic effects. Heavy metal hyperaccumulation by plants is a complex phenomenon. Hyperaccumulators are specialized plants that usually concentrate or uptake metals in their different tissues to intensity far greater than those present in the soil or in non-accumulating species growing nearby and can actively accumulate or concentrate massive quantity of one or more heavy metals/pollutants from the surroundings (Khan et al. 2010). Plants have an intrinsic ability to scavenge ROS generation through the enhanced production of antioxidants (Zhao et al. 2010). The antioxidant enzymes such as SOD, CAT, POX and APX are important components in preventing oxidative stress in such hyperaccumulator plants This review provides a brief outline of metal hyperaccumulation in plants along with information about different types of hyperaccumulator plant species and reveals information regarding stress tolerance in such plant species.

The use of plant species for cleaning polluted soils and waters named as phytoremediation has gained increasing attention since last decade, as an emerging cheaper technology. There are around 400 plant species known worldwide to accumulate metals in large amounts and these species are of interest for potential use in phytoremediation of metal contaminated soils (Memon and Yatazawa, 1984; Baker, et al. 2000; Pilson-Smits, 2005). About 300 years ago, plants were proposed for use in the treatment of waste water. At the end of the 19th century, *Thlaspi caerulescens* and *Viola calaminaria* were the first plant species documented to accumulate high levels of metals in leaves (Hartman, 1975). The idea of using Plants to extract metals from contaminated soil was reintroduced and developed by Utsunam yia, 1980 and Chaney, 1983, and the first field trial on Zn and Cd phytoextraction was conducted by Baker et al. 1991. Rhizofiltration is the removal of pollutants from the contaminated waters by accumulation into plant biomass. Several aquatic species have been identified and tested for the phytoremediation of heavy metals from the polluted water. These include sharp dock (*Polygonum amphibium L.*), duck weed (*Lemna minor L.*), water hyacinth (*Eichhornia crassipes*), water lettuce (*P. stratiotes*), calamus (*Lepironia articulate*), pennywort (*Hydrocotyle umbellate L.*) (Prasad and Freitas, 2003).

Some plants have the property to survive, grow, and reproduce on metalliferous environment polluted with heavy metals. They can tolerate high heavy metal concentration and take up large amounts of one or more heavy metals from surrounding environment into their shoot and leaves at concentration 100-100 fold higher than those non accumulator plant species. Such type of plant species can define as hyperaccumulators. Hyperaccumulators plants have evolved different strategies that control uptake, accumulation, and translocation of heavy metals into different plant tissues and finally detoxification and sequestration of these metals. (Das et al. 2012; Alkorta and Garbisu, 2001). In 1989, Baker & Brooks reported the identification of approximately 400 metal hyperaccumulating species from over 22 families, including the Asteraceace, Brassicaceae, Caryophyllaceae, Fabaceae, Poaceae and Violaceae. Hyperaccumulating thresholds for plants accumulating heavy metals, including Cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), lead (Pb) and zinc (Zn) as well as trace elements arsenic (As) and selenium (Se) were represented in table (Table2.1). Thresholds vary for different metals depending on average plant concentrations and abundance in the environment. (Brooks, 1987; Baker & Brooks, 1989).

Table 1 Heavy metals concentration in normal plant and the corresponding threshold value at which a plant can be considered a hyperaccumulator (Kabata-Pendias, Trace Elements in Soils and Plants, Edition 3, 2000.CRC Press, p 83)

Metal/ Trace element	Normal plant concentration range (µg g-1 DW)*	Hyperaccumulator threshold (µg g-1 DW)
Mn	**30 – 300**	**10000** (Baker and Brooks, 1989)
Zn	**27 – 150**	**10000** (Reeves and Brooks, 1983)
Cu	**5 – 30**	**1000** (Brooks et al., 1980)

Ni	**0.1 – 5**	**1000** (Brooks et al., 1977; Reeves, 1992)
Pb	**5 – 10**	**1000** (Reeves and Brooks, 1983)
Cd	**0.05 – 0.2**	**100** (Reeves and Brooks, 1983)
Co	**0.02 – 1**	**1000** (Brooks et al., 1980)
Se	**0.01 – 2**	**100** (Reeves and Brooks, 1983)
Cr	**0.1 – 0.5**	**1000** (Reeves and Brooks, 1983)
As	**1 – 1.7**	**1000**(Ma et al., 2001)

Heavy Metal Hyperaccumulation in Plants:

Heavy metal hyperaccumulation by plants is a complex phenomenon. The extensive root system of plants functions as a solar driven pumps, which concentrate and extract metals from soil and water. Metal hyperaccumulation depends on the capability to tolerate high amount of metals in the surrounding environment and within the plants tissues and cells.

An ideal hyperaccumulator plant would have shoots with a high capacity to accumulate heavy metals/metalloids, have a high biomass and rapid growth, and bioconcentration factor (BCF) and translocation factor (TF) values higher than 1 (Garbisu and Alkorta 2001). In particular, hyperaccumulators have a very high bioconcentration factor (BCF) as a result of their physiological make-up enabling active metal sequestration and concentration, and it has been suggested that this should be a critical factor in recognition of hyperaccumuators (Hobbs and Streit, 1986). BCF provides an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the surrounding medium (Zayed et al. 1998). TF is the ratio of heavy metal concentration in the shoot/leaf to that in the root of the plant (Luo et al. 2005). Translocation factor gives the shoot-to-root quotient of metal concentrations (or translocation ratio), and depicts the ability of the plant to translocate the metal species from roots to leaves at different concentrations.

Role of Antioxidant System in Metal Tolerance:

Cd and Cu toxicity induces oxidative stress by producing reactive oxygen species (ROS) such as superoxide radicals (O_2^{-}.), hydrogen peroxide (H_2O_2) and singlet oxygen ($^1O_2$) (Devi and Prasad, 1998), to mitigate and repair the damage caused by ROS, plants have evolved complex antioxidant systems

(Zhao et al. 2010). Antioxidant enzymes form a part of the battery of stress mitigation repertoire of plants against metal excess (Gill et al. 2010). Plants have diverse array of enzymes such as superoxide dismutase (SOD), ascorbate peroxidase (APX), guiacol peroxidase (GPX/POX), catalase (CAT) as well as low molecular weight antioxidants like cysteine, and ascorbic acid to scavenge different types of ROS, thereby preventing oxidative stress in plants (Gill et al. 2010).

SOD constitutes the first line of defence against oxidative stress. SOD is a metalloprotein that catalyzes the dismutation of superoxide to H_2O_2 and molecular oxygen in the cytosol, mitochondria and chloroplast of plants (Fridovich, 1986). SOD dismutates two superoxide radicals to H_2O_2 and oxygen and thus maintains superoxide radicals in a steady state. SOD can decrease peroxidation of membrane lipids and maintain cell membrane stability. CAT is a universally present oxidoreductase that decomposes H_2O_2 to water and molecular oxygen, and it is one of the key enzymes involved in the removal of toxic peroxides. POX is widely distributed in the plant kingdom and is one of the principal enzymes involved in the elimination ROS. POX catalyzes H_2O_2 dependent oxidation of the substrate. Van Assche and Clijsters, 1990 and Weckx and Clijsters, 1996 have proposed that the enhancement of some peroxidase and catalase activities may prevent oxidative damage, acting as peroxide scavengers. AP_X detoxify H_2O_2 using ascorbate for reduction. It is one of the major components of ASHeGSH cycle where it helps in the process of accumulation of toxic levels of H_2O_2 in plants (Drazkiewicz et al. 2003).

The response of antioxidative enzymes to Cd stress seems to vary among plant species and tissues. Cd-dependent augmentation of antioxidant enzymes in *B. juncea* were reported by Mobin and Khan, 2007 and Qadir et al. 2004. Cd-dependent augmentation of antioxidant enzymes in aquatic macrophytes were found in *Ceratophyllum demersum*, (Aravind and Prasad, 2003), *Lemna minor* (Balen et al 2011; Razinger et al. 2008). Further, induction of enzymes followed by inhibition was also observed in *Bacopa monnieri* (Mishra et al. 2006). Greater production of key antioxidant enzymes in a hyperaccumulator, therefore, acts as a tactic to strengthen the cell antioxidant system and manage the threat of ROS upsurge as a result of metal excess.

Conclusion:

Globally researchers have observed that some plant species can tolerate greater amount of heavy metal in their different plant tissues Metal accumulators are usually referred to as Hyperaccumulators that concentrate or uptake metals in their different tissues to an intensity far greater than those present in the soil or in non-accumulating species growing nearby The plant species generally used in phytoremediation technology should have the capabilities such as to accumulate the metal(s) destined to be extracted, preferably in the aboveground tissues such as shoot and leaf, have high tolerance to metal concentrations in the surrounding environment, rapid growth rate, high accumulating biomass, can be easily grown and fully harvestable. Moreover augmentation of cellular antioxidants enzymatic activities in such hyperaccumulation plant species to protect itself against metal induced toxicity were important for heavy metal detoxification and such augmentation may be inferred as a beneficial tool to counter ROS and confer better phytoremediation efficiency.

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