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DETOXIFYING HEAVY METALS: THE VITAL ROLE OF PHYTOCHELATINS IN PLANTS

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ABSTRACT:

Plants transitioned from aquatic to terrestrial environments several hundred million years ago and over the years have developed the ability to tolerate heavy metals as an adaptation to their environment. Since plants rely on the soil for nutrients and water, they have developed mechanisms to counteract the negative effects of leached heavy metals on their metabolism. One common response is the formation of metal-binding ligands known as phytochelatins (PCs). These cysteine-rich peptides are found in plants and yeast and are capable of binding and sequestering toxic metal ions, effectively detoxifying plant cells. In order to expand their biomass and make up for the land's lack of nutrients and water, they may therefore enhance both their photosynthetic activities and "suction pump" capacities. These traits of terrestrial plants would be a disadvantage, though, if there were an abundance of poisonous heavy metals in the soil, for example, arsenic, cadmium, copper and mercury, as the plants would have to accumulate them internally. To deal with such a detrimental effect brought on by the poisonous metals or metalloids in terrestrial settings, the plants may have to acquire novel tolerance traits. However, higher plants have persisted in terrestrial settings, indicating that they were able to maintain a variety of tolerances. There is growing evidence to suggest that a wide range of plant species can produce PCs. The ability of plants to remove heavy metals from soil and water plays a significant role in phytoremediation efforts in areas impacted by metal contamination.

Keywords: Phytochelatin, heavy metal, Plants growth

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INTRODUCTION

Heavy metal exposure causes oxidative stress in plants, which damages their cellular structure. Additionally, plants build up metal ions that interfere with cellular symmetry. Crop plants have developed a system to detoxify and to reduce the adverse consequences of heavy metal contact and build-up. These methods primarily rely on intra-cellular categorisation and chelation. Chelation of heavy toxic metals is a used in the detoxifying method that a variety of plants.

Phytochelatins (PCs) is part of the peptides family of Cys-rich and is a major class of heavy toxic metal chelators found in crop plants. Heavy metal toxins like Co, Cr, Pb, Cd, Cu, Zn, Ni, and As are mildly to highly contaminated fertilised soils in many parts of the world. This might be caused by the prolonged use of phosphatic fertilisers, the application of sewage waste, dust from refineries, industrial output, and improper irrigation of cultivable regions.

However, plants have evolved a highly effective defence system to deal with these problematic environmental heavy metal toxicity issues. Cysteine and Glutathione (GSH) and the two most significant and important low molecular weight biological thiols. Plants with strong affinity for heavy toxic metals produce low molecular weight thiols.

GSH namely contains sulphur and its synthesis is catalyzed by two major ATP reliant enzymes γ-glutamylcysteine synthetase (GSH1) and glutathione synthetase (GSH2). The detoxification of heavy toxic metals such as nickel and cadmium are essentially done by GSH, a substrate for phytochelatins synthesis. (Passariello et al. 2002)

Due to the possible negative ecological impacts of heavy metals, poisoning of cultivable soil by these substances has become a serious threat to environment. Because of their frequent prevalence and toxic consequences on plants cultivated in such soils, such toxic substances are regarded as soil contaminant.

In any cultivable land the maximum legal upper ceiling for the presence of toxic metal namely, cadmium (Cd) is 100mg/kg. (Salt et al,.2005)

Lead (Pb) is the most dangerous and widely available mineral in the soil due to the discharge of Pb-containing paints, petrol, even municipal sewage filth, paper and pulp and dangerous explosives.

Crop Plant morphology, growth, and photosynthetic processes are adversely affected by heavy metal presence. According to Sharma and Dubey (2005), a high amount of Pb also affects membrane permeability, water balance, enzyme activity, and mineral nutrition.

Lead (Pb) interacts with the enzymes of sulfhydril groups to decrease their reaction at the cellular level. Additionally, increased levels of Lead (Pb) concentration enhances oxidative stress in the crop plants which leads to more ROS being released.

In addition to Cd, fertilisers, discharge from municipal sludge and waste incinerators, by-products from the mining of metalliferous minerals, the metal smelting factories, and other human involvement also pollute cultivable soil with zinc (Zn).

Zinc (Zn) is a necessary nutrient for human beings, whereas Cd is optional and could be dangerous to higher crop plants, animals, and humans. Zn concentrations that are frequently higher than those needed as nutrients and may result in phytotoxicity can be found in contaminated soils. In contaminated soils, Zn values between 150 and 300 mg/kg have been recorded. (De Vries et al,.2007)

Phytochelatins

The characteristics of Phytochelatins and its heavy metal binding were examined on a dump yard at a historical copper mining site. When these heavy metal toxins are applied on Silene vulgaris and sensitive (tomato) cell suspension cultures, they result in the development of heavy metal-phytochelatin-complexes with Cu and Cd as well as the binding of Zn and Pb to compounds with lower molecular weights.

Since the Cd- and Cu-complexes evaporate in the roots of water cultures of Silene vulgaris between 7 and 14 days after heavy metal exposure, the binding of heavy metal ions to phytochelatins appears to play only a temporary function in the heavy metal detoxification. (Leopold et al,.1999)

The depletion of harmful heavy toxic metal (HM) concentrations in the cytoplasm and organelles is one of the most crucial mechanisms in higher plants' ability to tolerate HM. HMs frequently chelate or precipitate inside the vacuoles of receptive plants. Under HM-stress, sensitive and receptive cells can theoretically synthesise PCs. Both whole plants in water cultures and undi-er-entiated cell suspension cultures exhibit the same binding characteristics.

While Zinc and Lead ions are linked to a low molecular mass compound that has not yet been identified, Cu and Cd ions are mostly complexed with phytochelatin molecules.

The creation of HMPC-complexes is a quick and likely temporary response of the cells, and it is not important for the heavy toxic metal tolerance of crop plants, which can survive and thrive in HM-polluted soils naturally. Silene vulgaris (Moench) Garcke, ssp. humilis (Schubert) Rauschert plants were found growing in an old copper mine dump in the German town of Saugrund. For the water cultures, seeds from the same source were utilised. For four weeks, the plants were cultivated in Zindzadse solution in a controlled greenhouse environment with 16 hours of light and 8 hours of darkness, 248°C and 208°C, and a relative humidity of 55%. Cu2+, Cd2+, Zn2+, and Pb2+ were incubated with Silene vulgaris plants at concentrations of 0.1 to 0.5 mM; tomato plants were incubated at a concentration ten times lower. (Kon-ya et al,.1990)

When exposed to copper, Silene vulgaris plants from both non-receptive and copper-receptive groups both produce phytochelatins. The highest copper concentration at which phytochelatin (PC) content occurs and also the upper-limit copper concentration at which PC is induced both rise proportionately to copper tolerance levels. Both receptive and non-receptive plants exhibit similar phytochelatins (PC) concentrations in the root. This is also true for the F3 families, which are notably receptive non-segregating crosses between receptive and in-receptive plants. (Schat et al,.1992)

Heavy metal toxicity affects plants in many numbers of ways. These reactions involve the metal ions being immobilised, excluded, chelated, and compartmentalised, also the production of ethylene and stress proteins, crop plants exposed to Cd, which likely the greatest number and most comprehensive research have been conducted over many years. The development of plants as agents for the phytoremediation of contaminated places will depend in large part on our understanding of the molecular and genetic underpinnings of these mechanisms. (Schat et al,.2002)

The phytochelatins (PC) are the metal-binding peptides and have the structural formula (glucys)n (gly), (glucys)n (ala), (glucys)n (ser), (glucys)n (glu), (glucys)n (glu), (glucys)n (gluln), or (glucys)n (gln), where n ranges from 2 to 11.

Conclusion

The substrate for PC production is GSH (or, in some circumstances, similar molecules), as shown by a large number of physiological, biochemical, and genetic investigations. The purpose of PCs has been a topic of intense discussion. (Thumann et al,.1991)

The PCs are supposed to have a role in the cellular homeostasis of vital nutrients containing heavy toxic metals, especially Copper (Cu) and Zinc (Zn). Moreover, the minimal Cu and Zn contact levels needed to produce phytochelatins (PCs) at significant applications in crop plant cells are frequently far higher than normal nutritional needs or even very close to toxicity thresholds. (Grill et al,.1985)

References

De Vries, W., Lofts, S., Tipping, E., Meili, M., Groenenberg, J. E., & Schütze, G. (2007). Impact of soil properties on critical concentrations of cadmium, lead, copper, zinc, and mercury in soil and soil solution in view of ecotoxicological effects. Reviews of environmental contamination and toxicology, 47-89.

Grill, E., Winnacker, E. L., & Zenk, M. H. (1985). Phytochelatins: the principal heavy-metal complexing peptides of higher plants. Science, 230(4726), 674-676.

Gupta, D. K., Vandenhove, H., & Inouhe, M. (2013). Role of phytochelatins in heavy metal stress and detoxification mechanisms in plants (pp. 73-94). Springer Berlin Heidelberg.

Inouhe, M. (2005). Phytochelatins. Brazilian Journal of plant physiology, 17, 65-78.

Kon-ya, Y., Yoshimura, E., Yamazaki, S., & Toda, S. (1990). Identification of Cd-binding peptides of fission yeast Schizosaccharomyces pombe by FRIT-FAB LC/MS. Agricultural and biological chemistry, 54(12), 3327-3329.

Leopold, I., Günther, D., Schmidt, J., & Neumann, D. (1999). Phytochelatins and heavy metal tolerance. Phytochemistry, 50(8), 1323-1328.

Meuwly, P., Thibault, P., Schwan, A. L., & Rauser, W. E. (1995). Three families of thiol peptides are induced by cadmium in maize. The Plant Journal, 7(3), 391-400.

Passariello, B., Giuliano, V., Quaresima, S., Barbaro, M., Caroli, S., Forte, G., ... & Iavicoli, I. (2002). Evaluation of the environmental contamination at an abandoned mining site. Microchemical Journal, 73(1-2), 245-250.

Salt, D. E., Prince, R. C., Pickering, I. J., & Raskin, I. (1995). Mechanisms of cadmium mobility and accumulation in Indian mustard. Plant physiology, 109(4), 1427-1433.

Salt, D. E., Smith, R. D., & Raskin, I. (1998). Phytoremediation. Annual review of plant biology, 49(1), 643-668.

Schat, H., & Kol€ , M. M. A. (1992). Plant Physiol., 99, 1475.

Schat, H., Llugany, M., Vooijs, R., Hartley- Whitaker, J., & Bleeker, P. M. (2002). The role of phytochelatins in constitutive and adaptive heavy metal tolerances in hyperaccumulator and non-hyperaccumulator metallophytes. Journal of experimental botany, 53(379), 2381-2392.

Thumann, J., Grill, E., Winnacker, E. L., & Zenk, M. H. (1991). Reactivation of metal- requiring apoenzymes by phytochelatin—metal complexes.

FEBS letters, 284(1), 66-69.