Chapter 2

Hydrophytes and Heavy Metal Stress:

Mechanisms, Adaptations, and Phytoremediation Potential

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ABSTRACT

Heavy metals like cadmium (Cd) and arsenic (As) significantly affect hydrophyte growth, disrupting processes like photosynthesis and causing oxidative stress. Some species, such as Elodea canadensis (submerged) and Eichhornia crassipes (floating), act as hyperaccumulators, capturing metals at efficiencies exceeding 72.5% in contaminated environments. In contrast, species less tolerant to these metals exhibit toxicity through chlorosis, inhibited root elongation, and nutrient uptake failure. Hydrophytes employ tolerance mechanisms like chelation via phytochelatins and metallothioneins, antioxidant enzymes like superoxide dismutase, and reducing reactive oxygen species (ROS). Structural adaptations, such as iron plaque formation on Typha latifolia roots, immobilize metals effectively. Species

DOI: 10.4018/979-8-3373-4037-1.ch002

like Sedum alfredii promote metal translocation, while Lemna minor uses vacuolar sequestration and rhizosphere symbiosis to minimize metal bioavailability. Further studies are needed to understand long-term ecological impacts and genetic controls of tolerance mechanisms.

1. INTRODUCTION

As a result of anthropogenic activities, including mining processes, agricultural runoff, and industrial emissions, the increasing accumulation of heavy metals (HMs) in the water environment has become a pressing environmental concern. These metals, including cadmium (Cd), lead (Pb), mercury (Hg), chromium (Cr), nickel (Ni), and arsenic (As), are non-biodegradable and persist in the environment, being a threat to aquatic flora and fauna (P. Sharma & Dubey, 2005). Freshwater aquatic macrophytes, also known as hydrophytes, play a crucial role in maintaining the chemistry and physical habitat of aquatic ecosystems. They do this by retaining water quality, adding oxygen to the water column, and providing a habitat for diverse biotic communities. Heavy metal toxicity, which disrupts cellular homeostasis and metabolism, often has adverse effects on the growth and physiological development of organisms (P. K. Rai, 2009; Sytar et al., 2013). Heavy metals and hydrophytes. They have a complex relationship with heavy metals, including their absorption, translocation, accumulation, and detoxification (Figure 1). Certain hydrophytes have an unusual ability to withstand and even accumulate large quantities of heavy metals without suffering much damage, suggesting that they may be potential candidates for phytoremediation, and others are highly sensitive, as evidenced by reduced photosynthesis, enzyme activity, and biomass (DalCorso et al., 2019; Zhang et al., 2020). Conventional remediation methods are costly and hazardous; therefore, phytoremediation utilises plants to remediate contaminants (Sahoo et al., 2025). The use of hydrophytes (aquatic plants) in cleaning up heavy metals dates back to the 1970s. During the 1990s, phytoremediation gained popularity, particularly with metal-absorbing species such as *Eichhornia crassipes* and *Pistia stratiotes* (Bayuo et al., 2024). In the 2000s, researchers discovered that bioactive compounds, such as flavonoids, play a role in detoxification. Nanomaterials, genetic engineering, and interaction between plants and microbes have recently emerged as a cost-effective environmental cleanup option through phyto-remediation (Díaz-Torres et al., 2021). For instance, some species, including *Hydrilla verticillata*, *Lemna minor*, and Eichhornia crassipes, have demonstrated bioaccumulation potential and tolerance mechanisms (antioxidant systems, metals sequestration in vacuoles, and induction of metal-chelating phytochelatins) as well (Song et al., 2018). The ability of hydrophytes to respond to heavy metal-induced oxidative stress is a crucial component of their

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