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Mycoremediation of Potentially Toxic Trace Elements—a Biological Tool for Soil Cleanup: A Review

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ABSTRACT

Anthropogenic and geogenic activities release potentially toxic trace elements (PTEs) that impact human health and the environment. Increasing environmental pollution stresses the need for environmentally friendly remediation technologies. Physico-chemical treatments are effective, but are costly and generate secondary pollution on- or off-site. Phytoremediation is a biological treatment that provides positive results for PTE eradication with few limitations. Mycoremediation, a type of bioremediation to use macrofungi (mushrooms) for PTE extraction from polluted sites, is the best option for soil cleanup. This review highlights the scope, mechanisms, and potentials of mycoremediation. Mushrooms produce a variety of extracellular enzymes that degrade polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, dyes, and petroleum hydrocarbons into simpler compounds. Cadmium (Cd), lead (Pb), mercury (Hg), chromium (Cr), copper (Cu), zinc (Zn), and iron (Fe) have been effectively extracted by *Phellinus badius*, *Amanita spissa*, *Lactarius piperatus*, *Suillus grevillei*, *Agaricus bisporous*, *Tricholoma terreum*, and *Fomes fomentarius*, respectively. Mycoremediation is affected by environmental and genetic factors, such as pH, substrate, mycelium age, enzyme type, and ecology. The bioaccumulation factor (BAF) can make clear the effectiveness of a mushroom for the extraction of PTEs from the substrate. Higher BAF values of Cd (4.34), Pb (2.75), Cu (9), and Hg (95) have been reported for *Amanita muscaria*, *Hypholoma fasciculare*, *Russula foetens*, and *Boletus pinophilus*, respectively, demonstrating their effectiveness and suitability for mycoremediation of PTEs.

Key Words: bioaccumulation factor, bioremediation, extracellular enzymes, macrofungus, phytoremediation, pollution

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INTRODUCTION

Soil contamination has accelerated globally, which is due to industrial expansion, extensive chemical usage in agriculture, automobile exhaust, mine explorations, the natural pedogenic processes of weathering of parent materials, and the improper waste disposal practices of wastes containing high metal concentrations by industry, commercial establishments, and residential communities (Fang *et al.*, 2014). Common contaminants include potentially toxic trace elements (PTEs), pesticides, petrochemicals, and polycyclic aromatic hydrocarbons (PAHs) (Granero and Domingo, 2002; Huang *et al.*, 2007; Govil *et al.*, 2008; Fang *et al.*, 2014; Mohsenzadeh and Shahrokhi, 2014). Of these sources, PTEs are a major contaminant due to their cytotoxicity, mutagenicity, and carcinogenicity (Hamman, 2004; Mahavi, 2005). Many elements such as cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu), and selenium (Se) are toxic to living organisms even at low levels. The PTEs comprise 53 elements and are some of the most hazardous toxic substances found in the natural environment. Due to their persistence, non-biodegradable nature, high density ($>$ 5 g cm^{-3}), and introduction into the food chain, they can pose a lethal threat to human life and property (Beverwijk, 1967; Luo *et al.*, 2007; Sharma *et al.*, 2007; Rai and Tripathi, 2009; Zhao *et al.*, 2010; Miransari, 2011; Bharti and Banerjee, 2012; Bhattacharya *et al.*, 2014; Zhou *et al.*, 2014; ATSDR, 2015).

The adequate protection and restoration of soil ecosystems contaminated by PTEs require remediation technologies based on the development of effective physical, chemical, and biological approaches to address the rising risk of PTEs. Soil remediation, from an environmental perspective, is the reduction of the concentration of contaminants in the soil by physical, chemical, and biological treatments (Asiriuwa *et al.*, 2013; Bhattacharya *et al.*, 2014; Kulshreshtha *et al.*, 2014). Conventional soil remediation techniques inclu-

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de pneumatic fracturing, vitrification, stabilization, excavation, and removal of the contaminated soil layers, washing of contaminated soils with strong acids or heavy metal chelators, chemical precipitation, ion-exchange, adsorption, membrane filtration, and electrochemical treatment technologies. Most remediation techniques are expensive, laborious, and technically complex, cause soil physical, chemical, and biological disturbance, and generate secondary pollution, leading to their low acceptability among researchers (Volesky, 2001; Sharma, 2003; Bhargava *et al.*, 2012; Bharti and Banerjee, 2012). Plants and microorganisms have been used to remove toxic environmental contaminants, which is known as biological remediation. Biological remediation by bacteria, fungi, or algae is the most effective method for trace metal removal because it is a natural, environmentally friendly process, has a low cost, and is well-accepted by the public (Ali *et al.*, 2013). Biological remediation technologies include bioremediation, phytoremediation, bioventing, bioleaching, land farming, the use of bioreactor, composting, bioaugmentation, and biostimulation (Fig. 1). Among these technologies, bioremediation and phytoremediation are the most useful. These methods have advantages over physico-chemical methods because they preserve natural soil properties and are solar energy dependent. In bioremediation, trace elements are transformed into bioavailable forms *via* siderophores, organic acids, and biosurfactant production, biomethylation, and redox processes. Similarly, plant growth is boasted by phosphorus (P) solubilization, nitrogen (N) fixation, phytohormone, and 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase synthesis, which lead to higher plant biomass and ultimately assist phytoremediation (Beškoski *et al.*, 2011; Ullah *et al.*, 2015).

Many factors can limit the phytoremediation of contaminated soils, including plant selectivity, climate dependence, tolerance to PTEs, and secondary contamination by hyperaccumulators (Damodaran *et al.*, 2014). The growing concern over global pollution caused by PTEs stresses the need to develop biotechnologies to address this rapidly growing environmental pollution problem. Emphasis should be given to obtaining the maximum production/yield, reducing waste generation, and treatment/conversion of wastes into useful products for future use. Mycoremediation is a type of bioremediation technique in which fungi are used to decontaminate/clean a site by converting a polluted environment (usually soils contaminated with pollutants) to a less contaminated state. In mycoremediation, fungal mycelia play a vital role in the bioremediation process. The fungal decomposition process is performed by the mycelium. The mycelium secretes extracellular enzymes and acids that break down lignin and cellulose (*i.e.*, building blocks of plant fiber) and assist in solubilizing and complexing metal cations (Sesli *et al.*, 2008; Singh and Sharma, 2013; Damodaran *et al.*, 2014; Mani and Kumar, 2014). Mycoremediation studies have expanded the use of different fungi to clean the environment by extracting PTEs from soils.

Mushrooms, a specific group of basidiomycete fungi, which lack chlorophylls, are saprophytic, and feed on organic matter, can grow on logs (lignicolous), animal dung (coprophilous), agricultural wastes, lawns, *etc.* (Asiriuwa *et al.*, 2013). Mushrooms can be unicellular or multicellular, have a thalloid or filamentous structure, and reproduce asexually and sexually by spore production and gametes, respectively (Emuh, 2010). The success of mycoremediation depends on the ability of a fungal species to target a specific trace metal in the substrate. Most mushrooms produce extracellular enzymes and organic acids which break down complex substances into soluble substances for mushroom nutrition and are considered as good recyclers in nature (Mai *et al.*, 2004; Kuforiji and Fasidi, 2008; Zhu

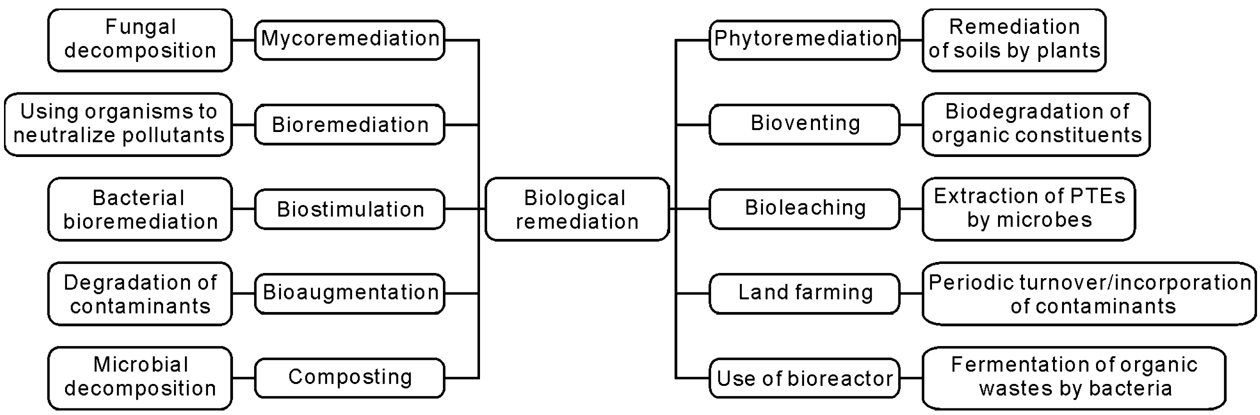

Fig. 1 Flow chart of biological remediation technologies for pollutants. PTEs = potentially toxic trace elements.