**Phytoremediation-Review on Biotechnological Approach for Remediation of**

**Emerging Pollutants**

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**ABSTRACT**

Exponential growth in human population, urbanization, and industrialization have led to a rise in environmental pollutants globally. These pollutants emerge as a result of the increase in human population as well as advancement in the use and application of agricultural chemical pesticides, medicinal drugs, personal care products (PPCPs), plastic polymers, and heavy metals. Although, the intent of this compound is to improve agricultural yields to ensure food and material supply to satiate the ever-growing need for a growing human population and also human health and better life in general. However, advancement in large-scale production of these compounds results in the generation and release of waste products to terrestrial and aquatic environments as a consequence of which this leads to devastating effects for the entire ecosystems. For addressing the environmental issue environmental-friendly and sustainable means of remediating contaminants is indispensable. To resolve this, biological strategy i.e. bioremediation (plants and microbes) can be utilized for removing this toxic material from the environment. However, extensive release of these pollutants which may be due to natural processes and human economic activity has a severe and challenging impact on the environment nowadays where leakage or accidental discharge of these hazardous contaminants are serious problems. The biodegradation capacity of the natural microbiome is insufficient in combating them. In this review, we will be focusing on the potential of plants and biotechnological exploitation for the improvement of plant’s ability to tolerate different pollutants and phytoremediation efficiency and highlight future challenges.

**Keywords**— phytoremediation, hyperaccumulator plants, transgenic plants, xenobiotics. oxidative stress

**I. INTRODUCTION**

The word “*Phyto*-” means plant, and “-*remediation*” means reversal of damage. Thus, phytoremediation is the use of plants to remediate or clean up environmental pollutants and involves growing plants in polluted areas to absorb or break down pollutants (1). It is considered as “Green Revolution” in the field of innovative cleanup technologies. The idea of using metal-accumulating plants to remove heavy metals and other compounds was first introduced in 1983, but the concept has actually been implemented for the past 300 years on wastewater discharges (69). There are different mechanisms by which plants remediate pollutants from the environment. Techniques of phytoremediation can be classified as (i) Phytostabilization- The use of plants to reduce the metal mobility in soil via absorption and precipitation, thus reducing their bioavailability. (ii) Phytoextraction- Process in which plants extract metals from the soil and concentrate them into roots and shoots (iii) Phytovolatilization- Process in which contaminants are taken up by the plants and through transpiration, evaporate into the atmosphere (iv) Phytodegradation- Degradation of organic pollutants to less toxic form in the soil or within the body of the plants (2-7).

Phytoremediation, a natural biological process for degrading xenobiotic and recalcitrant compounds that accumulate in the environment is an emerging, eco-friendly green engineering Phyto-technology where hyper-accumulator plants with their natural ability to remediate these pollutants are selected or are genetically engineered to improve their ability to tolerate as well as improve their ability to directly uptake pollutants from surface water, groundwater, soil, and sediments. Phytoremediation has received increased attention for sequestering and mineralizing organic and inorganic compounds present in contaminated soil which is of worldwide concern, and is applicable for a wide range of contaminants viz; heavy metals, radionuclides, organic compounds like chlorinated solvents, polycyclic aromatic hydrocarbons, pesticides/insecticides, explosive and surfactants, thus, prove to be an effective, economical and socially accepted technology (8-10). Conventional remediation technologies that use physiochemical and chemical methods methods are costly and difficult to implement, slow in the process, and emphasize separation rather than eliminating the hazardous substance from contaminated sites as a result of which causes a buildup of secondary pollutants damaging soil fertility that negatively impacts the agricultural environment (11,12). Plants and microorganisms have the ability to degrade pollutants and can survive in contaminated sites due to their metabolic capabilities [13, 14]. However, contamination by heavy metals, such as mercury cannot be remedied by the natural mechanism of microorganisms and plants. Heavy metals have carcinogenic effects and can cause DNA damage in humans and animals due to their mutagenic ability (15-17). Recalcitrant heavy metals are a potential threat as they are nondegradable and stay in the soil for centuries and cleanup of heavy metal contaminated sites is obligatory to abate entry of toxic elements into the food chain. Development of genetically engineered plants by transfer or overexpression of detoxifying genes or metal chelator genes into a candidate plant can improve the phytoremediation traits of hyperaccumulator plants (18-20), hence, could solve these problems.

**II. TRANSGENIC APPROACH FOR BIOREMEDIATION- USE OF TRANSGENIC PLANTS**

Genetically engineered organisms would be environmentally friendly and economical alternatives for the management and removal of pollutants in contaminated sites. A plant's cellular and molecular mechanism has the potential for pollutant detoxification which involves the removal of compounds or conversion of these compounds to biologically inactive forms. The use of hyper-accumulator plants for removing heavy metals and other compounds was introduced in 1983 (22). Plants have the ability to absorb pollutants from the soil through their roots and translocate them to the shoots (23). Some plants secrete compounds into root zones that can chelate metals assisting them in the solubilization and uptake of metals (24) where many genes are responsible. Introducing these genes responsible for mitigating pollutants in hyperaccumulator plants is crucial. For introducing hyperaccumulation traits to fast growth, high biomass plants, traditional breeding (plant hybridization) are employed (64). Transfer of the metal hyperaccumulation trait to high biomass plants is feasible through somatic hybridization. It has been reported that somatic hybrid, which have enhanced hyperaccumulation capability and tolerance derived from *T. caerulescens* and higher biomass production derived from *B. napus* (65), showed the ability to accumulate high levels of Zn and Cd. Genetic engineering has advantages over traditional breeding to modify plants with desirable traits for phytoremediation, moreover, can even transfer desirable genes from hyperaccumulator to sexually incompatible plant species(66,67), therefore, has shown positive prospects in the field of phytoremediation. Using *Agrobacterium* *tumefaciens*-mediated plant transformation these genes can be introduced and expressed in recipient plants (25). Genes responsible for metal uptake, removal, translocation, and bioaccumulation have been identified (26-28) and transgenic plants which have the ability to degrade xenobiotics with enhanced metal uptake, translocation, and sequestration have been developed by transferring or overexpressing these genes into candidate plants (29). It has been reported that transgenic plants can degrade chlorinated solvents, explosives, and phenol substances (30-32). Transgenic cauliflower where the Yeast CUP1 gene has been introduced accumulates cadmium 16-fold higher than the untransformed cauliflower (33, 34). Two novel rice genes HPP (heavy metal-associated plant protein) and HIPP (heavy metal-associated isoprenylated plant protein) tolerant to Cu, Zn, Cd, and Mn have been identified (33). Expression of vacuolar proton pump (V-PPase) with a Na/proton antiporter (NHX1 transporter) enhances Cu tolerance and accumulation in transgenic tobacco (34). Cytochrome P450 genes expressed in transgenic plants has the potential to remove pollutants from soil and water (35). Bacterial biphenylchlorophenyl dioxygenase gene, bphC gene, CYP71A10, Mn peroxidase gene, pentaerythritol tetranitrate reductase (onr) gene expressed in tobacco plants, basic peroxidase (tpxl) gene expressed in tomato plants, Cytochrome P450 monoxygenase (XplA and XplB) gene expressed in *Arabidopsis thaliana* have been generated as potential tools for phytoremediation of hazardous contaminants (36-41). Bacterial merA gene was introduced into the roots of *A. thaliana* which allowed the absorption of this ion and the reduction of this toxic mercury into less toxic volatile mercury (42). Transgenic *B. juncea* in which c-glutamylcysteine synthetase was overexpressed revealed higher tolerance and accumulation of Cd, Cr, Cu, Pb and Zn than wildtype plants (43). Transgenic Arabidopsi*s* plants could transport oxyanion arsenate to above ground, reduce to arsenite and sequester it into thiol peptide complexes by transfer of *E. coli* Ars C and γ-ECS genes (21). Heavy metal tolerance is determined by the strength of oxidative stress defence system of the plants. Excessive production of ROS resulting in oxidative stress may be initiated by heavy metals. To enhance antioxidant activity by overexpression of genes involved in antioxidant machinery is the most common strategy to increase heavy metal tolerance (68). Altered oxidative stress-related enzymes may result in enhanced metal tolerance (44). Insertion of xenobiotic degradation genes into the root system of transgenic plants degrades pollutants from contaminated sites ( 45-46). It was found that ethylene levels were reduced by expressing ACC in transgenic plants (47). Phytotoxic nitroaromatic explosives are recalcitrant to non-transgenic plants. Bacterial genes involved in toxic degradation when expressed in transgenic plants, it was found out that the plant tolerance to pollutants increased, thereby, phytoremediation of this nitroaromatics could more readily be improved with the use of transgenic plants. (48). It was reported that metal transporter genes such as ZAT and CAX-2 genes in transgenic plants enhanced the accumulation of zinc, calcium, cadmium, and manganese (49,50). Oxidative stress-related enzymes when altered may result in enhanced metal tolerance (51). Aluminium (Al) toxicity can cause inhibition of root elongation (52-56). AtGR1 gene expressed in transgenic plants was observed to show more rapid root elongation in plants treated with various concentrations of Al compared with types plants under the same treatment indicating that AtGR1 gene expression moderated AI-induced root growth inhibition, through the alleviation of Al-induced oxidative stress in transgenic plants which proves to be an efficient approach to enhance Al tolerance (57). Identification and introduction of metal transporter genes encoding transporter molecules to enhance the metal ions absorbing capacity of plants is a promising phytoremediation approach. Several plant metal transporters have been reported, some of which include Arabidopsis IRT1 gene encoding protein that regulates the uptake of iron and other metals (58) and MRP1 gene encoding Mg-ATpase transporter (59). Co-expression of two bacterial genes arsenate reductase (Ars C) and y-glutamylcysteine synthetase (y-ECS) in Arabidopsis plants, showed substantially greater arsenic tolerance than wild-type plants or plants expressing y-ECS or Ars C alone (60). YCF1 yeast protein which detoxifies Cd by transporting into vacuoles overexpressed in Arabidopsis thaliana showed enhanced tolerance and accumulated greater amounts of Cd and Pb (61).

**III. Perspective**

The existence of hazardous toxic substances in the environment has an excessive negative impact on the overall health of living organisms. The persistent nonbiodegradable nature of heavy metals could enter the food chain which might result in the rapid accumulation of these pollutants in living organisms through biomagnification (63). It also decreases soil richness altering nutrient cycling. Thus, efficient, environmental friendly and economical technologies are indispensible to promote detoxification in the recovery of affected biomes and for mitigation of pollutants from contaminated sites. Identification of promising plant species and specific gene for detoxification and then transferring those genes to other species using genetic engineering tool can significantly enhanced the detoxification capabilities of hyperaccumulator plants as a result of which it can lead to more effective contaminated sites reclamation. Already existing scientific studies of several genes and the use of techniques for pollutant degradation provide hope for developing novel transgenic plants with improved tolerance to heavy metals and for detoxification or degradation of toxic substances into recipients with increased adaptability. Discovering novel genes that can break down new contaminants is an urgency to create new transgenic organisms that can remediate pollutants in a proficient manner as the industry continues to grow and there is an exponential increase in the amount of toxic material generated from these industries on a consistent basis. For the eco-rehabilitation of toxic recalcitrant substances, phytoremediation proves to be a promising technique. Further investigations must be carried out in this area to enhance our knowledge to identify genes and clarify metabolites and their mechanisms and their capacity to combat pollutants using modern scientific technology which can aid in discovering novel genes and metabolites for efficient phytoremediation of pollutants by transgenic hyper-accumulator plants (62). Understanding the underlying mechanism of the intrinsic detoxification methods, phytoremediation using transgenic plants will provide environmental friendly alternative to conventional remediation methods.

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