transporters, particularly for inorganics, which depend on uptake on transporter proteins. Organics, when moderately hydrophobic, can o en pass membranes passively and do not need transporters. If it is known which transporters mediate pollutant uptake and translocation, these may be overproduced in plants. Plant tolerance, in turn, may be limited by the abundance of enzymes that modify, degrade, or chelate pollutants, or general antioxidant enzymes. Depending on the suspected limiting factors, any such enzymes may be over-expressed to enhance phytoremediation capacity. In addition to boosting the expression of existing genes, novel genes may be introduced from other plant species or any organism. In this way, a totally new phytoremediation capacity may be introduced into a suitable plant species for phytoremediation. All of these approaches have been used successfully [7].

Role of Biotechnology in Phytoremediation

An ideal phytoremediator would have: high tolerance to the pollutant; the ability to either degrade or concentrate the contaminant at high levels in the biomass; extensive root systems; the capacity to absorb large amounts of water from the sosm4(e)-5(div-6(h)4v0 Tw (a)9(r)8(eh0.4)]TJ0.l p)7(l)-fymsm4(e)4trodt an
t u8(2ap2(r.a t)6(o)11(tk)99(r)8(g(d))19acc)18(g umn)3(.1(sf)-6e)-5(di)-3(a)19(t)7(l a)8.998(2 Td[(p)-9(o)7(l)-5(l)12(u)12(r)6(s,(n)4(csce)-4.9(d in)(t a
ti9(17y)512(td3f) yadi.9-(ta)ah.eol gg[(n,26a)s fo11pa.95sm4c, c,3((e)-5(d4(l gg.1i(l crct(e c.)(p yI5169(r12(d4c, c,11pa)8 fdui9(h6ah-8.(rct(e c.]l gg.1i(ef

can result in volatilization of selenium compound [21]. Selenium is an essential nutrient for many organisms including humans, but is toxic at elevated levels. Selenium de ciency and toxicity are problems worldwide. ere is no evidence that Se is essential for higher plants, but due to its similarity to sulfur Se is readily taken up and assimilated by plants via sulfur transporters and biochemical pathways. Plants accumulate Se in all organs including seeds, and can also volatilize Se into the atmosphere. Some species can even hyperaccumulate Se up to 1% of their dry weight. e ability of plants to accumulate and volatilize Se may be used for phytoremediation.

In a rst approach to manipulate plant Se tolerance, accumulation, and/or volatilization, genes involved in sulfur/selenium assimilation and volatilization were over-expressed. Brassica juncea (Indian mustard) over-expressing ATP sulfurylase (APS), involved in selenate-to-selenite conversion, showed enhanced selenate reduction, judged from the nding that transgenic APS plants supplied with selenate accumulated an organic form of Se while wild-type plants accumulated selenate [14]. e APS transgenic accumulated two- to three-fold more Se than wild-type, and 1.5-fold more sulfur. e APS plants tolerated the accumulated Se better than wildtype, perhaps because of the organic form of Se accumulated. Selenium volatilization rate was not a ected in the APS transgenics. Indian mustard over-expressing cystathionine gamma synthase (CgS, the rst enzyme in the conversion of SeCys to SeMet) showed two- to three-fold higher volatilization rates compared to untransformed plants [22].

Mercury (Hg): Mercury is a highly toxic element found both naturally and as an introduced contaminant in the environment, and is a very serious global environmental problem. Organic mercury (organomercurials), the most toxic form to living organisms, is produced when bacteria in the water and soil convert elemental mercury into methylmercury. Methylmercury is easily absorbed and accumulates at high levels in the food chain. Mercury poisoning a ects the immune system, damages the nervous system, and is harmful to developing foetuses [21]. Terrestrial plants are generally insensitive to biodegradation encodes a novel, fused avodoxin-cytochrome P450 enzyme [34]. Transgenic Arabidopsis plants expressing xplA (CYP177) from Rhodococcus rhodochrous 11Y tolerated and removed high levels of RDX, whereas non-transgenic plants did not take up any signi cant amount. e xplA transgenics grew in soils containing 2000 mg kg^{2}1, a level nearly ten times higher than non-transgenic plants could tolerate. In recent studies, co-expression of both xplA and xplB in transgenic plants resulted in even greater improvements in RDX removal rates, 30-fold higher than with xplA alone [34]. Since military sites are co-contaminated with both TNT and RDX, plants with the ability to detoxify both types of explosives would be desirable. Poplar plants with nfsI and xplA have increased removal of both TNT and RDX, and triple transformants with xplA, xplB, and nfsI are being constructed.

Pesticide: Since pesticides can cause chronic abnormalities in humans and they generally lead to reduced environmental quality, multiple methods including incineration and land lling have been used to remove this class of pollutants; however, these physical methods are expensive and ine cient. Bioremediation using microorganisms capable of degrading the polluting pesticide and enhanced phytoremediation of pesticides using transgenic plants are emerging as more e ective solutions [35]. Transgenic plant technology is investigated to improve remediation of pesticides. In research by Ref. [26], the atzA gene encoding the rst enzyme, atrazine chlorohydrolase, of a 6-step pathwaene

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response to trichloroethylene (TCE) in a transgenic poplar. Functional & Integrative Genomics 10: 417-424.

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