Efficiency of transporter genes and proteins in hyperaccumulator plants for metals tolerance in wastewater treatment: Sustainable technique for metal detoxification

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A B S T R A C T

Environmental contamination of heavy metals is now becoming increasingly a concern and a significant problem due to its harmful effects worldwide. The plant-meditated approach is encouraging to eliminate toxins avoiding side effects from polluted wastew-ater. For the development of appropriate plant species for the mechanisms of heavy metal absorption, transport, detoxification, identification, and signaling pathways would be important facts. Transporter genes like ATP-phosphoribosyl transferase (ATP-PRT), Yellow Stripe-like (YSL), NAS (nicotinamide synthase), SAMS (S-adenosyl-methionine synthetase), FER (ferritin Fe (III) binding), HMA (heavy metal ATPase), IREG (iron-regulated transporter), and proteins like cation diffusion facilitators (CDF), ZRT, IRT-like protein (ZIP), and natural resistance-associated macrophage protein (NRAMP) are active in heavy metal accumulation, translocalisation, sequestration, and resistance. Besides, chelating agents and metabolites can be used either to increase heavy metal bioavail-ability, which facilitates heavy metal accumulation in plants and further promote plant growth and fitness. This review paper addresses key roles and potential transporter genes and proteins for the remediation of heavy metals from hyperaccumulator plants. This review specifically focuses on the efficacy of transporter genes and proteins in hyperaccumulator plants in metal restoration, discussing the use of these plants for wastewater treatment processes.

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1. Introduction

Environmental pollution from industrial sludge and wastewater containing organic and inorganic toxins is becoming a global problem in the agriculture and aquatic ecosystem (Bhargava et al., 2012; Sharma and Rath, 2020; Sharma and Singh, 2021; Sharma, 2021). The industrial sector is a major consumer of both natural resources and an environmentally harmful contributor. Heavy metals enter into the water in from industries, including mineral mining, water processing, metal forming, metal coating, batteries, nuclear power industry, and nuclear energy (Kamarudzaman et al., 2015; Sharma et al., 2020a). The industry's development is a significant factor in rising environmental pollution (Esmaeili and Beni, 2015; Tripathi et al., 2021a,b). Discharged wastewater from different industries cause harmful effect on plant and animal by high pollution parameter of total dissolved solids (TDS), chemical oxygen demand (COD) total suspended solids (TSS), biochemical oxygen demand (BOD), ions (Na^+, P^+, and K^+) along with the high concentration of metals (Chandra et al., 2018; Sharma et al., 2020b). These pollutants cause serious soil and water pollution also can lead to severe health risks such as genotoxic, cancer, mutagenic, and teratogenic in nature in living organisms because of their non-biodegradable and persistent nature (Ngo et al., 2020). Heavy metal ions accumulate in the organ of live plants and animals in the environment polluted by toxic chemicals (Huang et al., 2018; Benson et al., 2018; Sharma et al., 2020c). The heavy metals discharged by the different industrial activities eventually become environmentally sustainable, especially urban surface waters (Khadse et al., 2008). Certain plant species have the potential to survive and reproduced in metallic soils, with high tolerance, i.e., hyper resistance of heavy metals in growth substrates against typically toxic levels. The high concentration of metals in soil affects the physicochemical properties of soil and also affects the biomass, health, and production of crop plants (Patra et al., 2020; Zhang et al., 2020). Few plant species in nature can absorb or detoxify extremely high As amounts. Plants in hyperaccumulators have taken several methods to facilitate removal, build-up, and hyperaccumulation of harmful chemicals (Ghori et al., 2016).

Plant capacity to aggregate and tolerate how to plant remediation technologies can be developed for improving food safety (Ha et al., 2011). Phytoremediation residue of *Brassica napus L.*, *Pennisetum sinese*, and *Lolium perenne L.* have the potential for remediation of Cd. A few plant species which belong to the family of *Pteridaceae*, were known as As hyperaccumulators (Delil et al., 2020). *Isatis cappadocica* is a plant present in Iran which, as a resistant mechanism includes an increase in the synthesis of thiol and chelation with PCs and glutathione (Karimi et al., 2009). In the list of top hazardous pollutants, arsenic is the most toxic metalloids, which cause mutagenic and carcinogenic effects in the living organisms (Sodhi et al., 2019). The fern of *Pteris vittata* has potential for As V and As III uptake in their shoot via translocation and vacuole sequestration (Xie et al., 2009; Danh et al., 2014). However, As is absorbed near the walls of the vascular stem bundles in the root cells and did not cause any major alteration in the cells and tissue of the *P. vittata*. Energy-dispersive x-ray microanalysis demonstrated that As is mostly present in *P. vittata* epidermal cell vacuoles.

More than 45 families including in both tropical and temperate zones distributed throughout the world as the hyperaccumulators plant have been found which shows that this trait has changed more than once independently. Hyperaccumulators plants that accumulate >1 mg/g (0.1%), Cr, Ni or Pb, $>$ 0.1 mg/g (0.01%), Se and Tl >10 mg/g (1%), Zn (0.3%), >0.3 mg/g (0.05%), Co or Cu in the shoot and leaves (Reeves et al., 2017). There are 721 hyperaccumulators in the worldwide database of hyperaccumulators (www.hyperaccumulators.org) and the number is continuously increasing every day. Over five hundred thirty-two group of hyperaccumulators are known as Ni hyperaccumulators, while 7 species are Cd hyperaccumulators and 5 species are As most endangered species of human health (Reeves et al., 2018; Sharma et al., 2021a,b). Heavy metals cause a toxic effect on the plant's reproductive system like sperm, gamete, and embryo as well as also effect on aquatic life like the hatching of the egg, physical abnormality in fishes, and death of larvae (Fatima et al., 2014). Various species of fishes are highly affected by pollution like a disturbance in endocrine hormones, genetic abnormality, and oxidative stress (Luszczek-Trojnar et al., 2014; Javed et al., 2016). Metals decrease hematological parameters and glycogen stores, anemic, rendering fish frail, and susceptible to disease (Javed and Usmani, 2015). Informing reactive oxygen species (ROS), metals can cause oxidative stress, which disrupts the biochemical mechanism, contributes to humans cell disturbance (Jaishankar et al., 2014). The decrease to trivalent chromium (Cr^{3+}) and hexavalent chromium (Cr^{6+}) is documented to cause human cancer and cellular damage, allowing free radicals to cause damage to DNA also (Mishra and Bharagava, 2016).

Detoxification of metal-polluted area is highly required for environmental and animal health. Several metals like Fe, Cu, Zn, and Pb are played a key role in plant health at the limit concentration (Angassa et al., 2018; Wu et al., 2019). Hyperaccumulator species can uptake and translocate metals in their cell wall, vacuole, plasma membrane, and other tissue in higher concentration. Several plant species such as *Canna indica, Cassia tora, Imperata cylindrical,* and *Arundo* *donax* are used to remove various ions and nutrients (Zhu and Banuelos, 2017). *Phragmites australis* and *Typha latifolia* are the most commonly used hyperaccumulator plants due to elevated biomass, a thick network of the root, and rapid purification (Kumari and Tripathi, 2015). Various environmental factors affect metal absorption, like temperature, soil pH, plant type, capacity for soil cation exchange, size, root system, metal bioavailability, soil moisture, etc (Cai and Lytton, 2004). Some metal cations are more soluble and usable in pH 5.5 soil and this has led to results research into the introduction of acidifiers in soils contaminated with metals enhance plant-mediated detoxification, but only a few works reported on these topics, and sufficient treatment is required. The availability and solubility of metal ions depend on the pH value of soil and water and which is the main factor for the bioavailability of metals in subtracting. It has been documented that many metal cations are more soluble and usable in low-pH soils (Raskin and Ensley, 2000). Potential plants have multidisciplinary mechanisms and biochemical activity for remediation of metals polluted soil (Shah and Daverey, 2020). Waste disposal of polluted heavy-metal areas with hyperaccumulators offers a promising alternative to conventional environmental strategies (Sun et al., 2008).

Given the above, this review article, hence, aims to analyze and discus the effectiveness of transporter genes and proteins in hyperaccumulator plants for the phytoremediation of wastewater containing metals and metalloids. It presents an in-depth analysis of both traditional and innovative approaches of phytoremediation, assesses their efficacy in eliminating toxic chemicals from the contaminated environment, examines recent scientific developments and evaluates global phytoremediation research trends for greater awareness and its approval as a technology of sustainable remediation strategy.

2. Metal and metalloids translocation in hyperaccumulators plants

Heavy metal contamination in the environment is becoming increasingly a challenge because of the adverse effects all over the world. Heavy metal contamination was caused mainly by anthropogenic activities caused by the mining of metal, smelting, casting and other metal-based industries, the leaching of waste from various sources, e.g. sites of waste, dumping, excretion, sewage sludge, automobile runoffs, vehicles, and highways. Metalloids start to form covalent links, which reveal toxicity (Briffa et al., 2020). Two main effects of this feature they can bind with an organic group of covalent bonds. Thus, compounds and lipophilic ions can form, and toxic effects can be produced by binding cellular macromolecules to non-metallic elements. As metalloids are lipophilic, their toxic response and distribution within the biosphere differ from the simple ionic forms of the same component. Important bio-agents for both the removal of toxic metals and metalloids are being strongly related to improving environmental and ecosystem health (Rai, 2019).

Many plant species that survive and grow in a highly toxic metal-containing environment are characterized as hypertolerance against high tolerance (Manara et al., 2020; Sharma et al., 2020d). Hyperaccumulator plants are specialist plants with at least two characteristics features. The first thing that can happen is that these plants have aerial tissue that accumulates some metals or metalloids at levels hundreds or thousands longer than usual. Compared to the non-hyper accumulative families of the Brassicaceae plants, the two hyperaccumulators have enhanced many physiological processes leading to metal hyperaccumulation, like increased root cell metal uptake, decreased root vacuole root metal sequestration, rapid and effective root shot loading, and significantly enhanced capacity to root-to-shoot translocation. Genetic studies of slow-growing hyperaccumulator plants have provided us with a broader understanding of the accumulation mechanisms of heavy metals and an excellent understanding of the genes that are good for over-expression and conversion among organisms. Plant breeding and geneticist are now able to use various bioengineering instruments to improve the phytoextraction ability of hyperaccumulator plants gene bypassing metal tolerance to high biomass plant species (Kamnev and van der Lelie, 2000).

Hyperaccumulators have a broad variety of techniques to address environmental factors and to reduce the adverse effects of metal toxicity to cope with environmental stresses. The potential reactions involve significant changes in gene expression, in particular membrane transporters, which are responsible for absorbing, translocating, and sequestrating the minerals and nutrients. This method can be categorized into four categories: (1) root to shoot transfer; (2) heavy metal transportation to root; (3) metals chelating; and (4) remediation in the vacuole. The metals access has to abilities of tissues of root cells rapid and immediately carried to the plants' above-ground components to successfully removing toxins. Although the plants grow in a medium that can have high heavy metal concentrations, just a tiny part would be bioavailable. Due to its strong binding like Pb and less solubility like Hg, Sn, Ag, and Cr o the bioavailability of the metals is limited. Rhizospheric micro-organism and root exudates like organic acids, protons, and siderophores may affect the bioavailability of the heavy metals in soil (Marschner, 2012). In the aerial part of the hyperaccumulators detoxification by transporting metals to inactive cell walls, vacuoles, and cell walls are the primary feature of ligand binding (Haydon and Cobbett, 2007). Vacuole particularly for the Zn and Cd ions and the vacuole compartmentalization is an essential resistance system of heavy metals hyperaccumulators. For instance, Ni hyperaccumulators T is split into the vacuole of leaf ion metal transfer protein (TgMTP1) is the major effect in the accumulation of metal in shoot vacuoles (Kramer et al., 2000). The effective trans-localization of heavy metals employing the gene overexpression, which codes transportation mechanism from root to shoot and it is depending heavily on efficient xylem loading systems (Hanikenne and Nouet, 2011) (see Fig. 1).

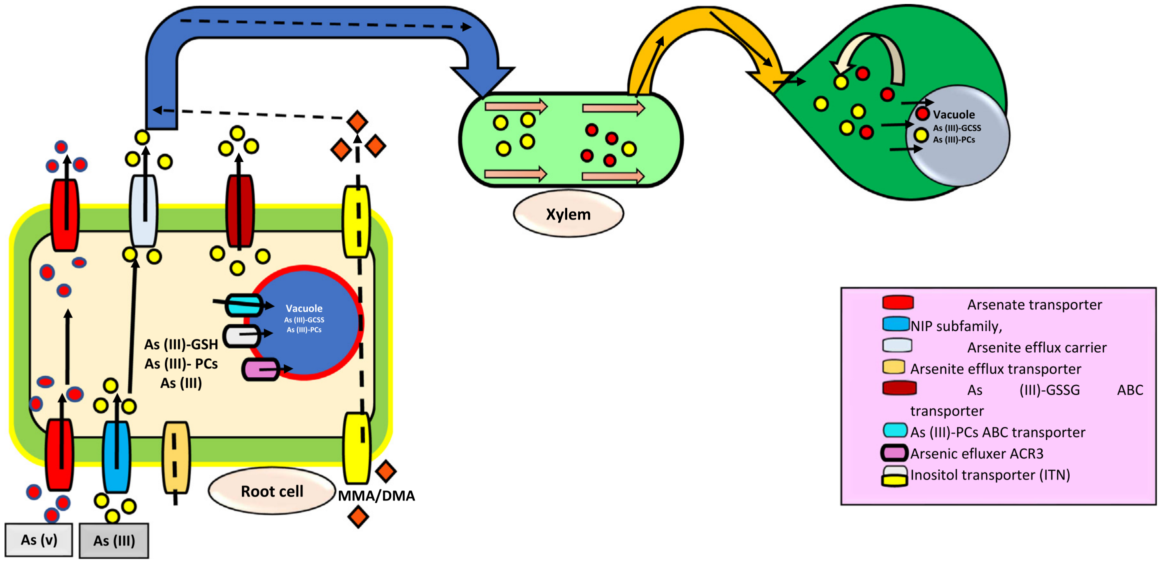

Fig. 1. Accumulation, translocation, and detoxification Arsenic (As) in plants. Arsenate (As V) accumulate can occur via arsenate transporters. Arsenate reductase (AR) reduces As (V) to Arsenite (As III) by using glutathione (GSH) as a reductant. Arsenic methylated species (DMA/MMA) uptake is carried out by unknown transporters. Phytochelatins (PCs) and GSH coordinate with As (III) to form a variety of complexes which are sequestered in vacuoles by ABC-type transporters.

2.1. Reactive oxygen species detoxifying metals toxicity

Plants have potential machinery from rapid growth and adaption in biotic and abiotic stress conditions. The first mention of a plant that is capable of accumulating extreme Ni content in soil and 1 mg/g dry weight of accumulated in the shoot of *Alyssum bertolonii* plant grown in Tuscany, Italy (Minguzzi, 1948). Such plants are primarily annual herbs, shrubs, or small trees, which are endemic in the tropical and temperate world, both in high-metallic soils. Plants that grow on metal-polluted land can be subdivided into three types: plants for the exclusion of metals, which do not allow large quantities of metal to reach the plants above ground and uptake a high concentration of metals inside the roots. Metal accumulators depend on metal concentration in the substrate that is considerably higher in their overground tissues than in the soil or in the nearby species that are not accumulated. Some potential grasses like *Pennisetum americanum* (L.), *Pennisetum purpureum* , and *Schumach* showed remediation of Zn and Cd (Zhang et al., 2010). The hyperaccumulator plants can be divided into two classes, obligatory and facultative based on metal accumulation and tolerance (Kramer, 2010). The species that are native to metals containing soil and are often more in metal at the hyperaccumulation stage are known as mandatory acquisition species. The facultative hyperaccumulators are species where some entities are hyperaccumulators as well as other individuals are not (Pollard et al., 2002). In several plant species have developed both independently and together with the capacity for tolerating and accumulating high levels of heavy metals to unusually high concentrations (Kramer, 2010). The basic characteristics of hyperaccumulator plants seem to be an increased rate of metals absorption in the root, highly efficient root-to-shoot translocation, greater capacity to uptake and sequester heavy metals in the leaf (Verbruggen et al., 2009). The reported data showed more than five hundred plants are identified as hyperaccumulator properties (Assuncao et al., 2003). Moreover, *Phragmites communis* shows high antioxidant activity and metals (Fe, Zn, Cu, Cr, and Cd) accumulation in their root and rhizome from paper industry sludge and wastewater (Hu et al., 2019; Sharma et al., 2020e). The efficiency of *Helianthus annuus* from Pb contaminated soil shown great potential as phytoremediation (Chauhan et al., 2020). *Phragmites karka* and *Eichhornia crassipes* have potentiality of removing COD (95%;), suspended solids (94%), and color (79%) from coffee industry effluent, which had total suspended solids of 399.3 mg/L, color of 1730 ADMI, and COD value of 13,000 mg/L (Said et al., 2020) (see Table 1).

3. Genetic expression and their regulation

Many species have developed to metalliferous environments defined as hyperaccumulators, gaining the capability of adapting and tolerating high concentrations of hazardous chemicals in their shoots without any harmful effect. In different areas of study, such as Zin-dependently-supposed global transcriptional control, transcriptional deregulation, and higher gene copy number for metal homeostasis of the hyperaccumulator *Arabidopsis halleri*, how and why certain plants can accumulate or tolerate high levels of potentially toxic compounds (Talke et al., in 2006). Usually, hyperaccumulator plants absorb metals in the aerial part by bulk flow from root to shoot in the xylem. The metals must first be translocated into the xylem apoplast from the root symplast, and in most cases, the transporting proteins involved in this process were

Table 1
Hyperaccumulator plants accumulation of metals from contaminated sites.

Heavy metals	Plants	Reference
Cd, Pb, Zn	*Helianthus annuus*	Angelova et al. (2016)
Hg	*Axonopus compressus*	Liu et al. (2020)
As, Cu, Pb, Zn	Spartina maritime	Mesa et al. (2015)
Zn, Cd, Pb	*Minuartia verna*	Bothe (2011)
Zn, Cu, Mg	*Phragmitis*	Sharma et al. (2020e)
Pb, Zn, Cd	*Viola boashanensis*	Zhuang et al. (2005)
As	*Pteris vittata*	Nalla et al. (2012)
Pb	Helianthus annuus L.	Chauhan et al. (2020)
Hg	*Pteridaceae Pteris vittata*	Su et al. (2008)
Fe, Cd, B, and Cr	*Eichhorina crassipes*	Eliah et al. (2014)
Zn, Cd and Pb	*Brassica napus, Glycine max*	Delil et al. (2020)
Pb	*Sedum alfredii Euphorbiaceae*	Chen et al. (2013)
Cu, Fe, Pb, Zn	*Euphorbia cheiradenia*	Nematian and Kazemeini (2013)
Ni	*Alyssum bertolonii*	Mengoni et al. (2012)
Ni	*Alyssum murale*	Broadhurst and Chaney (2016)
Cd, Zn	*Arabidopsis halleri*	Zhang et al. (2017)

not known. This is an inefficient method that is restricted but all by the number of transportation proteins available but also by the difference in transport speed, substratum affinity, and substrates. Metal may be deposited at the tissue level in the epidermis, while these excess metals at the cells are usually stored at the vacuole or the cell wall at the cellular level. Chelators are supposed to play a role and even bind by way of metals in metal detoxification.

There may be some genomic fine examples of four of the gene highest levels in the transcriptions *A. halleri*, heavy metal ATPase4 (HMA4), ZIP9, ZIP6, and ZIP3. The ZIP6, ZIP3, and ZIP9 genes are the metal carriers from the ZIP family and metal influx for cytoplasmic root, although HMA4 (At2g19110) is identified in *A thaliana* as P1B-type, ATPase, the role in root-to-shoot zinc transportation of metals (Guerinot, 2000; Hussain et al., 2004; Colangelo and Guerinot, 2006). The replication of these genes into the *A. halleri* genome could explain the more expression in HMA4 (Hanikenne et al., 2008). The four genes of this type have metal transport is regulated in hyperaccumulator plants including *A. halleri*. After all, heavy metals produce severe illnesses of toxicity in the plants at high levels and therefore regulated exclusively by plant cells for uptake and metabolism (Singh et al., 2012; Srivastava et al., 2012; DalCorso et al., 2013). Certain heavy metals, like Cr, Cd, Hg, Pb, and Al, but are non-essential and have no biological function and this is toxic at even low concentrations (Mills et al., 2003; Ernst et al., 2008; Hayat et al., 2012; Gill et al., 2013). The various transcriptomic analysis shows *A halleri* or *N. caerulescens* and their non-hyper-accumulative equivalents using the *Arabidopsis thaliana* microarray system have shown increased expression of genes controlling numerous key steps of metal transport and chelation (van de Mortel et al., 2006). The evolution of RNA-seq technologies has allowed the assessment of the global gene expression of hyperaccumulators, and this research indicates that the elevation of gene expression may be efficient and structured that contributes to the action of different hyperaccumulators (see Figs. 2 and 3).

3.1. Transporter proteins

The transport of metal ions to the vacuole from the cytoplasm, apoplast, and endoplasm reticulum are involved in expressing the proteins such as CDFs (Kramer et al., 2007). The primary function is to safeguard metal immune function in the nucleus, but some species like DmeF in *C metallidurans* and FieF in *E coli* appear to become a part of the resistance device (Grass et al., 2005). In plants all known transporter protectins are intracellular, particularly tonoplastic membranes; however, recent evidence supports the position of the conveyor protein in the plasma membrane, trans-Golgi, pre vacuolar, and endoplasmic reticular membranes (Hall and Williams, 2003; Yuan et al., 2012). Transcriptomic analysis of shoot and root showed which in *A halleri*, AhMTP1 transcripts are constitutively higher than in *A thaliana*, particularly in leaves, and can complement the zrc1cot1 mutant yeast mutant Zn-sensitive phenotype (Becher et al., 2004). There are five MTP1 paralogs in *A halleri* genome, located at four loci, and with one copy not set in the analyzed population (AhMTP1-D). In tandem, AhMTP1-A1 and AhMTP1-A2 are duplicated and thus related, while AhMTP1-B, AhMTP1-C, and AhMTP1-D are duplicated segmentally. The variants of highly accumulated MTP1 transcripts in the shoot are AhMTP1-A1/AhMTP1-A2 and AhMTP1-B loci, upregulated at high root Zn concentration and associated with Zn hypertolerance (Shahzad et al., 2010). AhMTP1-B was less competent than AhMTP1-C and AhMTP1-D even though all five copies were able to confer Zn tolerance on zrc1cot1 mutant yeast. These findings show that while replication of MTP1 loci in *A halleri* may be the basis of Zn tolerance, the five metal transporter genes appear to be undergoing individual state fates. A few MTP proteins have been fully functionally characterized and their subcellular location remains uncertain. Further work is also needed until the functions are completely understood by all the family members.

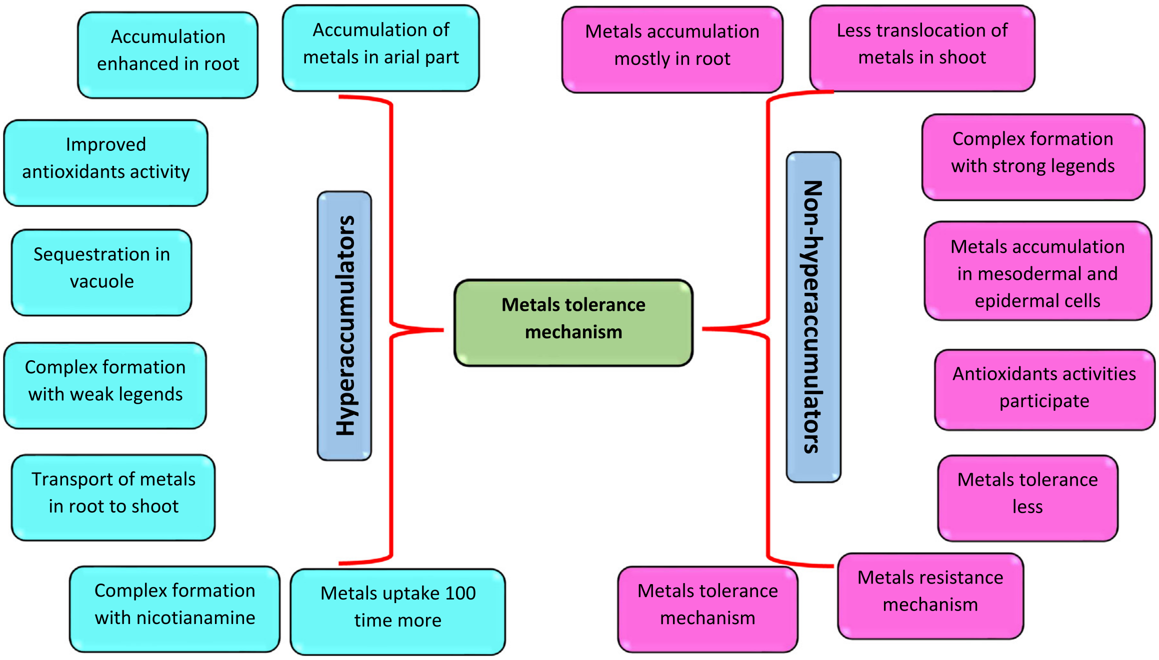

Fig. 2. Heavy metal accumulation and tolerance mechanisms in hyperaccumulator and non-hyperaccumulator.

3.2. Metals chelators

Chelators are organic molecules with high-affinity ligands that can bind with metals and perform an especially significant function in a living organism like transferrin, hemoglobin, phyto chelators, and metabolites from the microbial community (Kontoghiorghes, 2020). Several natural antioxidants contain metal-chelating features, including plant nutraceuticals. Phyto chelators such as 8-hydroxyquinoline, ellagic acid, curcumin, and quercetin, respectively. Equally, many phytochelatins, like silibinin, caffeic acid, maltol, phytic acid, and fisetin, do not only play a role in antioxidant activity but also play important role in physiological processes, such as the transportation and distribution of metals in other parts (Kontoghiorghe et al., 2015; Kontoghiorghes and Kontoghiorghe, 2019). Plants also catalyzed the redox reactions and change the chemical structure of metals to prevent the build-up of toxic metal ions. The reduction of As^{5+} to As^{3+} in *B. Juncea* and Cr^{6+} to Cr^{3+} in *Eichornia crassipes* (Pickering et al., 2000). In various oxidation states, some heavy metals do not exist and therefore have to be detoxified by chelation. In various oxidation states, some heavy metals do not exist, and therefore have to be detoxified by chelation. Organic acids, phytochelatins (PCs), amino acids, and metallothionein are the main ligands responsible for chelation (Memon and Schroder, 2009; Verbruggen et al., 2009). Many hyperaccumulation metals are believed to be ligand-bound, and even though some parts of ligand detoxification are being found are still unknown in plants, various chelators are involved in different phases of the metal transportation and storage process. The major intracellular chelators for cadmium are phytochelatins that accumulate in the vacuole in *C reinhardtiii* (Hu et al., 2001).

Improving absorption, translocation, resistance, and high accumulation of metals in accumulator plants is associated with organic acid ligands (Boominathan and Doran, 2003). Ligands like citrate or malate could be found vacuole of plant leaf with a maximum concentration of metal. The capacity of organic acid inverters to regulate their ability to accumulate metal. The largest malate concentration in the *T caerulescens* was followed by succinate, oxalate, and citrate. The plant shoot soluble Zn showed a clear association with both oxalate and malate. In *A halleri* aerial organs Zn forms complexes with malate, while in the non-hyperaccumulating, non-tolerant *Arabidopsis lyrata*, it occurs as Zn phosphate (Sarret et al., 2002). In *A halleri* aerial organs Zn forms complexes with malate, while in the non-hyperaccumulating, non-tolerant *Arabidopsis lyrata*, it occurs as Zn phosphate (McNear et al., 2010). Nickle was mainly found as an organic complex in the vacuoles of *T goingense* probably with citrate (Kramer et al., 2000). Cd/Zn hyperaccumulator for the moderately Cu-tolerant *N* caerulescens, substantial Cu compared to Cu-sensitive persons are bound to oxalate (Mijovilovich et al., 2009). The hyperaccumulator eco-type S Alfredii demonstrated that organic acids were responsible for improved mobility of Cd. Ni chelation with citrate has been shown to improve Ni net transport using Mg-ATP-energized root tonoplastic vesicles. Plants have antioxidant security mechanisms consisting of enzyme and non-enzyme molecules, which reduce excess production of ROS in cells (Mittler et al., 2004). The resistance capacities of metal hyperaccumulators have been reported to be contributing to the tolerance of metal oxidative stress injected by the metal-inducing oxidative stress, ascorbate, carotenoid, α-tocopeholes, flavonols, phenols, and proline and enzymatic antioxidants superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) (Zhang and Evans, 2013).

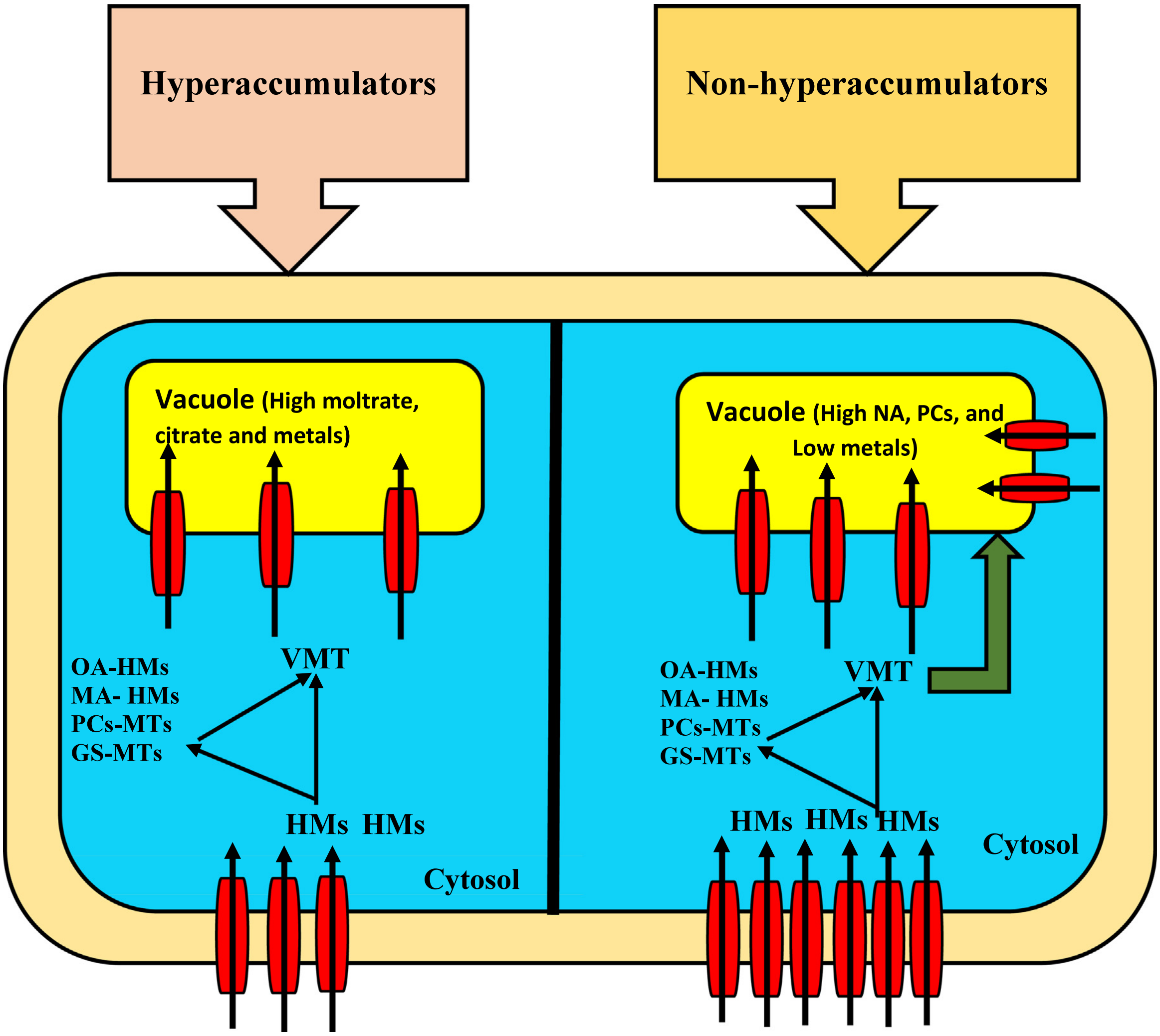

Fig. 3. Vacuolar sequestration mechanisms in hyperaccumulators and non-hyperaccumulator. Chelators as well as their transporters regulate the sequestration of heavy metals in the vacuoles. HM, Heavy metals; VMT, vacuolar metal transporters; AA, amino acids; OA, organic acids; NA, nicotianamines; MTs, metallothiones; PCs, phytochelatins; GS, glutathione.

3.3. Transporters

Metals are important for plants, but if over-accumulated, they can be harmful. Members of the YSL metal transporter family play an essential role in plant Fe homeostasis, and over several years a great deal of evidence was already collected that demonstrates the importance of YSLs in the long-distance transport of nicotianamine (NA) complexed metals. Members of the family TcYSL3 and TcYSL5 in the roots and shoots of *N caerulescens*, where they participate in vascular loading and translocation of nicotinamine–metal complexes, and YSL7, are constitutively overexpressed. Nicotianamine is formed by NA synthase (NAS) in all plants from 3 S-adenosyl-methionine (SAM) and forms powerful complexes with most transition metal ions. There is confirmation of NA participation in metal hyperaccumulation, as higher transcription rates of many NAS genes were reported in both *A halleri* and *Noccaea caerulescens* (Mandakova et al., 2015). Compared to *A thaliana, A Halleri*, the accumulator plant has been found to have higher NA content along with higher AhNAS 2 transcript and root protein levels and higher AhNAS 3 transcription levels in the shoots. Research conducted with *Thlaspi* offers evidence that nicotianamine is involved in hyperaccumulation in *Thlaspi*, but not Zinc, and that Ni and Fe fight for NA adsorption (Callahan et al., 2006). The reaction of the plant to Ni caused the deposition of NA in the roots, which is most likely a result of all this efflux from the leaf.

The CDFs belong to a family of universal drives intolerance and metal homeostasis. The efflux of transition metal cations, such as Zn^{2+}, Cd^{2+}, Co^{2+}, Ni^{2+}, and Mn^{2+} from the cytoplasm to the outside of the cell or into subcellular compartments is catalyzed by these proteins. The majority of CDFs proteins are supposed to be cytoplasmic and His-rich network between transmembrane domains IV and V; a series of signatures between domains I and II of the transmembrane as well as a domain of cation efflux consisting of transmembrane domains I to VI of transmembrane domains (Gaither and Eide, 2001). The use of iron in higher plants is classified as two techniques. The first is the technique of decrease occurring in all plants, except gramineous monocots, and consists of the following 3 steps: (1) the acidization of the soil employing H^{+}ATPases, to solubilize iron; (2) reduction of ferric iron (Fe(III)] by plasma membrane-ferrous chelate reductase; A broad family of membrane proteins, cation X changer (CAX) is divided into real calcium cation exchanger (CCX) and CAX (CAX1-CAX6). In Cd, every CAX groups probably require vacuolar sequestration. The overexpression of two genes like AtCAX2 and AtCAX4 in root vacuole enhance the transportation of Cd^{2+} in the vacuole (Korenkov et al., 2007). Many transporters are helped in vacuolar sequestration of different xenobiotics and metals are in the ATP-binding cassette (ABC). Members of the subfamilies of multidrug resistance-associated proteins (MRPs) are absorbed by the active transport of heavy metal chelating agents. There is a strong indication of the role of trace metal homeostasis in the sequestration of vacuoles (Henriques et al., 2002).

The detoxification of heavy metal ions in aerial parts of the hyperaccumulators is largely due to the ligand-binding and elimination of cytoplasm by moving metals into inactive compartments, vacuoles, and cell walls. The vacuole is the storage site for Cd and Zn ions and certain metal hyperaccumulators compartmentalization of metals in the vacuole is an important part of their process of resistance. Besides instance, most of the Ni was compartmentalized into leaf vacuole in Ni hyperaccumulator *T goingense,* and the high expression level of metal tolerance protein (TgMTP1) metal ion transporter is considered to be the key factor responsible for high metal uptake in shoot vacuoles (Persans et al., 2001). The effective sequestration of Zn and Cd by the MTP1 transporter into the shoot vacuoles seems to play a role in both hyper tolerance and hyperaccumulation (Ricachenevsky et al., 2013). At least partially, the vacuolar sequestration characteristic relies on the constitutive overexpression of genes that encode proteins that pass heavy metal via the tonoplast and are involved in the cytoplasm exclusion of heavy metals. The multidrug and toxin efflux family (MATE) is another form of transport protein involved in heavy metal translocation in hyperaccumulator plants (Rascio and Navari-Izzo, 2011). A member of the ferric reductase defective 3 (FDR3) family is constitutively expressed in *N caerulescens* and *A halleri* roots and is located at the root plasma membrane pericycle. It is involved in the citrate xylem influx, which is important for Fe transport as a ligand, but the overexpression of FDR3 in hyperaccumulators shows that it can play a role in the translocation of several other metals, like Zn (van de Mortel et al., 2006).

Histidine is used in heavy metal chelation and is the most important amino acid that plays a large function in metal ion homeostasis in plants. Amino acids including glycine (Gly), histidine (His), glutamic acid (Glu), and cysteine form a heavy-metallic amino acid complex in plants used in hyperaccumulators (Sharma and Dietz, 2006; Singh et al., 2019). In-plant hyperaccumulation, histidine plays an essential role. ATP-PRT is considered to be active in the control of His free levels and the extremely high Ni resistance *Alyssum* species of hyperaccumulator, which is the first His biosynthetic pathway enzyme ATP-PRT (Ingle et al., 2005). The complex is stable and highly concentrated in the roots of the metal hyperaccumulators like Cd, Zn, and Ni (Wycisk et al., 2004). His and NA were reported to play an important function in hyperaccumulation (Leitenmaier and Kupper, 2013). His concentration is significantly greater in Ni hyperaccumulators than in non-accumulators. A nicely greater degree of free His has been seen in the roots compared to non-accumulator of *Brassica juncea* (Kerkeb and Kramer, 2003). This indicates that additional factors for Ni xylem loading in A thaliana are needed. Most of the Ni in xylem sap of the *Alyssum*-hyperaccumulator plants was shown to be hydrated Ni^{2+} (Centofanti et al., 2013). The characterization of proteins involved in the uptake and accumulation of metals is an essential step to understanding the mechanism of high metal content tolerance mechanisms (Talke et al., 2006) (see Tables 2 and 3).

4. Response of microRNAs

The significant development and yield-limiting factor for plants are metal and metalloids stress. Plants employ diverse gene regulatory pathways under heavy metal stress. As an effective post-transcription modulator of gene expression, MicroRNAs (miRNA) are 21-nucleotide non-coding small RNAs (Ding et al., 2020). High-performance sequencing has newly resulted in the discovery in plants of the growing number of heavy-metal reactant microRNAs. A multiplicity of biological processes, which includes heavy-metal reception and conveyance, protein folding and assembling, metal chelation, oxygen reactive scavenging organisms, hormones signaling, and microRNA biogenesis are driven by metal regulated microRNAs and their target genes. MicroRNAs are separate small RNAs for plants that play a key role in various biological processes like environmental stress in many plant species. The detection and analytical findings of miRNAs that react to various metal toxins presented us all with adequate knowledge for understanding the control of a variety of metal tolerance enzymes and proteins. Sufficient evidence has been developed for the active involvement of miRNAs during toxicity reacting by integrating computational and multiple laboratory approaches, for example, through the regulation of different transcription factors and genes that coded proteins involved in plant growth. Even more, the investigation is required to understand the function and objectives of miRNAs, primarily transcription factors in signaling plant response pathways to the changes in the environment. Good knowledge of the process of miRNAs in metal stresses can aim to effectively build recommendations for enhancing crop stress resistance.

MicroRNAs consists of $\sim$20–24nt for the plant, which is not endogenous for small RNAs (Bartel, 2004). The function of eukaryotes as post-transcriptional regulators and have reportedly played an important part in modulating gene expression in plants. For various biological processes in plants, modulation of target gene expression through miRNAs is essential.

Table 2
Metals distribution in different cell organelles in hyperaccumulator plants.

Plants	Plant parts	Metals	Reference
Thlaspi goesingense	Cell wall	Ni	Kramer et al. (2000)
Elsholtzia splendens		Cu	Yang (2002)
Sedum alfredii H.		Zn	Kramer et al. (2000)
Sedum alfredii H.		Pb	He et al. (2003)
Thlaspi caerulescens	Epidermal	Zn	Yang et al. (2005)
Thlaspi caerulescens		Zn	Yang et al. (2005)
Alyssum		Ni	Yang et al. (2005)
Arabidopsis halleri	Mesophyll	Zn	Yang et al. (2005)
Sedum alfredii H.		Cd	Xiong et al. (2004)
Arabidopsis halleri	Trichome	Zn, Cd	Yang et al. (2005)
Brassica juncea		Cd	Yang et al. (2005)
Alyssum lesbiacum		Ni	Yang et al. (2005)
Thlaspi caerulescens	Vacuole	Zn	Yang et al. (2005)
Thlaspi caerulescens		Cd	Vazquez et al. (1994)
Sedum alfredii H.		Zn	Yang et al. (2005)
Sedum alfredii H.		Zn	Kramer et al. (2000)

Table 3
Role of genes in metals tolerance and accumulation in hyperaccumulator plants.

Hyperaccumulators	Metals	Gene family	Gene	Reference
A. lesbiacum	Ni	Histidine biosynthesis	ATP-PRT	Ingle et al. (2005)
A. halleri	Cd	Metallothionein gene	AhMT2b, AhMT3	Chiang et al. (2006)
T. caerulescens	Zn, Cu	Metallothionein gene	TcMT1, TcMT2	Roosens et al. (2005)
T. caerulescens	Ni	YSL transporter gene	TcYSL3, TcYSL5, TcYSL7	Feng Gendre et al. (2007)
S. nigrum	Fe, Cd	YSL transporter gene	SnYSL3	Feng et al. (2017)
S. plumbizincicola	Cd	YSL transporter gene	Sp YSL	Peng et al. (2017)
A. halleri	Zn	Nicotianamine synthase gene	AhNAS2, AhNAS3, NAS4	Deinlein et al. (2012)
T. caerulscens	Zn	Nicotianamine synthase gene	AhNAS2, AhNAS4	van de Mortel et al. (2006)
T. goesingense	Co, Zn,	Glutathione biosynthesis	TgSAT	Freeman and Salt (2007)
A. halleri	Cd	Ascorbate glutathione	APX and MD AR4	Chiang et al. (2006)
T. caerulescens	Cd, Zn	ZIP transporter gene	ZNT1, ZNT2, ZTP1, full length transcript of TcIRTI, TcZNT5-LC, TcZNT6-LC,	Wu et al. (2019)
A. halleri	Zn	ZIP transporter gene	AhZIP6, AhZIP9, TjZnt1, TjZnt2	Weber et al. (2004)
T. caerulescens	Zn	Cation diffusion facilitator transporter gene	TcMTP1, TcMTP8, TcMTP11	van de Mortel et al. (2006)
A. halleri	Zn	ABC transporter protein gene	AhMRP2	Becher et al. (2004)
T. caerulescens/N. caerulescens	Fe, Cd	NRAMP transporter gene	TcNRAMP4, NcNRAM1	Milner et al. (2014)
A. halleri		NRAMP transporter gene	AhNRAMP3	Weber et al. (2004)
T. japonicum	Ni	NRAMP transporter gene	TjNRAMP4	Mizuno et al. (2005)
T. caerulescens	Cd	Heavy metal ATPase transporter gene	TcHMA4, TcHMA3	Ueno et al. (2011)
A. halleri	Cd, Zn	Heavy metal ATPase transporter gene	AhHMA3, AhHMA4	Hanikenne et al. (2008)
S. plumbizincicola	Cd	Heavy metal ATPase transporter gene	SpHMA2, SpHMA4, SpHMA3	Liu et al. (2017)

Note — ZIP, (ZRT, IRT-like proteins); NRAMP (natural resistance-associated macrophage proteins); ABC, (ATPbinding cassette); YSL, (yellow stripe like).

There were two primary types of small RNAs in plants, which are microRNAs (miRNAs) and small RNAs (siRNAs). MicroRNAs consists of single-stranded precursors of RNA willingly creating additional hairpin complexes in the form of the DICER-LIKE1 RNase III enzyme (Chen, 2009). In plants, miRNA-oriented target cleavage can often induce dsRNA production, this process is done by a Dicer protein to produce siRNAs known as siRNAs (ta-siRNAs) (Axtell et al., 2006). Previously, a list of miRNAs that are involved in metal tolerance has emerged as important modulators of plant-adapting responses to stress conditions (Gupta et al., 2014). Classified 84 miRNAs of 37 miRNA families from the Cd-treated and non-treated B, preserved and unpreserved. Napus, including 19 miRNA participants not previously known (Zhou et al., 2012). Many miRNAs were analyzed separately in roots and shoots, or DNA damage regulated. Two small RNA libraries were developed using Solexa sequencing technologies and the Cd-free roots of radish-seedlers and several primary sensitive proteins and heavy metal enzymes were established as target transcripts for certain conserved miRNAs. For example, Rsa-miR156 targeted a transcript encoding a glutathione S -transferase 5 (GST5), whereas Rsa-miR393 targeted phytochelatins synthase1. These results indicate that the detoxification and mediation of the Rsa-miR156 and Rsa-miR393 can be carried out by direct monitoring of the GST5 and the PCS1 (phytochelatin synthase 1) Radish genes, respectively. miR395 is also another conserved small RNA that controls the assimilation and distribution of sulfate in many plant species such as *B napus*. Furthermore, Rsa-miR159 and Rsa-miR166, respectively, targeted iron transporter-liken protein and ABC transporter proteins. These conclusions demonstrate that in-plant Cd uptake and translocation Rsa-miR159 and Rsa-miR166 could play the important function of controlling its appropriate goals. A total of nine miRNA families were seen to be decommissioned under Cd stress under the approach miRNA microarrays, including miR156, misR162, miR 168, miR166, miR171, miR396, miR390, miR1432, and miR444. It now becomes clear that the secondary effects of compromised cellular homeostasis as a consequence of metal stress continue to be discovered in future trials if these established metal-regulatory miRNAs precisely modify their expression for adjustment and resistance to metal stress. We will strengthen our understanding of plant responses to metal stress by more data with miRNAs and their part in metal uptake and resistance.

5. Future perspectives

The interest of biologists, geochemists, and environmental scientists in plants that accumulate metallic elements to exceptional concentrations in their tissue has been considerable in recent years. Many plants can take toxic contaminants and natural pollutants from soil, and water with this regular capacity (Jeevanantham et al., 2019). These plants can provide useful insights into essential pathways for the sequestration, absorption, and translocation of metals. A variety of techniques for the production of transgenic goods with sufficient phytoremediation qualities have arisen, the easiest and most direct being the over-expression of the genes involved in heavy metals mutability, absorption, and transportation. HMA4 gene was one of the most significant candidates for hyperaccumulation to improve root-to-shoot translocations, as many lines of inquiry have shown its function in the loading of metals in xylem and this role in hyperaccumulators plants. MicroRNAs are a unique class of small RNAs in plants that play an important role in a variety of biological processes, including environmental stress on different species of plants. The discovery and study of miRNAs that react to the various toxic metals have given us enough knowledge to understand the control of certain metal tolerance enzymes and proteins. Additional research is required to explain the function and goals of miRNAs in signaling the mechanisms of plant response to environmental changes. The success of phytoremediation depends on the capability of plants to tolerate and accumulate multiple metals as soils are often contaminated with numerous metals. MTPs can be used in transgenic plant growth, which is more resistant to metal-poor soils and grows more resistant cultivations. The aims for future research and production of phytoextracted transgenic lines are all the genes that help in the absorption of metals from soil or waster. However, this is important that the application of a single gene would not lead to a perfect cell and further study into the metal battery route is required to understand the methodological principles of all the hyperaccumulators. The multiple genes concerned for the accumulation and tolerance of various metals can lead to transgenic plants that can remediate metals in the water and soil. The knowledge is a valuable context for research in the future on plant transporter genes and proteins.

Conclusion

This review presents state-of-art development and technological perspectives for the use of hyperaccumulators plants due to their excellent capacity to absorb and tolerate metals in their shoot and leaves at high concentrations without any toxic effect. It discussed the strategies adopted by the hyperaccumulators plants such as increasing the expression of abundance and enhancing the functions of key genes and proteins in comparison to non-hyperaccumulator plants. Various transporting proteins and genes are involved in the hyperaccumulation mechanism of metals by absorption, translocation, sequestration process from polluted environments. Hyperaccumulator plants also show a unique potential of synthesizing high rate of biomass and transporters of metals accumulators gene. The physiological and biochemical parameter and genetic basis of metal hyperaccumulation and related hypertolerance have been specifically discussed for *Arabidopsis halleri, Noccaea caerulescens, Thlaspi caerulescens,* and *Brassica nigra.* These information can facilitate better design of studies on metal accumulation for environmental protection.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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