

Review Article

A review on regulatory control of chromium stress in plants

Priyanka Yadav

Department of Biochemistry, MD University, Rohtak-124001 (Haryana), India

Asha Sharma

Department of Botany, MD University, Rohtak-124001 (Haryana), India

Sandeep Singh*

Department of Biochemistry, MD University, Rohtak-124001 (Haryana), India

*Corresponding author. E mail: ssingh.biochem@mdurohtak.ac.in

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Abstract

Chromium (Cr) is a non-biodegradable heavy metal that persists long in aquatic and terrestrial ecosystems and enters the food chain. It is cytotoxic even at low concentrations and reduces the yield of plants. Plants also have cellular mechanisms to manage the accumulation of metal ions inside the cell to diminish the possible injury from non-essential metal ions. This paper reviews current information on plant response to Cr, a key environmental pollutant. The harmful effects together with absorption, transfer, and aggregation of Cr are discussed. The roles of the cell wall, plasma membrane, and plant microbes as the primary hindrances for Cr ingress into the cell, along with sequestration and compartmentalization process, have also been discussed. Cr-generated oxidative injury is also regarded as the main deliberated effect of Cr toxicity. It interferes with NADPH oxidases (plasma membrane) and the electron transport chains, which develop electron leakage. Some genes related to Cr stress in plants get expressed, and suppression produces protective effects by activating the signal transduction pathways. The expression of genes like BnaCnng69940D and BnaC08g49360D is increased, which is involved in protein kinase activity, signal transduction, and oxidoreductase activity. The increased mRNA levels of Cr stress response proteins, including HSP90-1 and MT-1, have been reported in the *Brassica napus* plant. The stressed environment around the plants may stimulate the biosynthesis of phytochelatins and metal-binding proteins, which have a protective role in plant's growth and development.

Keywords: Abiotic stress, Chromium, Heavy metals, Oxidative stress, Phytochelatins

INTRODUCTION

In recent history, the total arable land area has diminished because of the population pressure and soil degradation by the industrial revolution and modern lifestyle. Lavish human activities have assisted the difficulties of atmospheric pollution by toxic metals (Singh *et al.*, 2013; Shahid *et al.*, 2017). Due to the quick expansion of factories and metropolitan regions, a broad range of pollutants like organic/inorganic compounds and heavy metals (HMs), etc., are regularly spreading in the environment (Ram *et al.*, 2019) with eventual harmful impacts on biological entities (Sharma *et al.*, 2019; Hashem *et al.*, 2020; Saleem *et al.*, 2020a). Among these heavy metals, chromium (Cr) is a well-known pollutant and carcinogen that is fatal for plants and animals (Sharma *et al.*, 2020). Effects of Cr depend upon plant species, valance state, amount, and

time of its exposure (Hose *et al.*, 2016). It exists in variable oxidation numbers starting with Cr²⁺ to Cr⁶⁺. Both forms (Cr³⁺) and (Cr⁶⁺) are prevalent and have more reliable oxidation numbers in the biosphere (Shahid *et al.*, 2017; Singh and Prasad, 2019). The reactive oxygen species (ROS) generation, followed by oxidative stress, is the primary harmful effect of chromium in plants. Several investigations have suggested that Cr induces oxidative cellular damage directly via the Fenton reactions (Gomes *et al.*, 2017; Yu *et al.*, 2018; Patra *et al.*, 2019) and indirectly by affecting the activities of the enzymes (Ahmad *et al.*, 2020; Sharma *et al.*, 2020; Wakeel *et al.*, 2020). Phytotoxic effects due to overproduction of ROS under Cr stress have been documented in *Brassica napus* L. (Gill *et al.*, 2015), *Triticum aestivum* L. (Ali *et al.*, 2015), and *Chenopodium quinoa* Willd (Scoccianti *et al.*, 2016). The occurrence of Cr³⁺ in a small fraction supports the metabolism of

sugars and lipids. The Cr^{3+} form responded more toward expressed genes in roots than in shoots (Feng *et al.*, 2019). Cr stress also raised the levels of proteins in plants that are important for intracellular membrane-bound organelles, nitrile hydratase activity, cytoskeleton protein binding, and stress responses (Gill *et al.*, 2016). The crop plants absorb oxidized states of HMs (Cr, Pb, Cd, As, Hg, Ni), which lead to toxicity and reduction in nutrient content. So, there is a need for critical analysis of toxic HMs (Cr) and successfully developing efficient techniques for removing HMs from food chains.

Heavy metals' toxicity

HMs (heavy metals) are classified as essential metals (Co, Fe, Mn, Mo, Ni, Zn, Cu, Mg) used as micronutrients in the biological system and non-essential metals (Pb, Cd, As, Cr, Hg) having no role as nutrients, both types toxic even at very low concentrations (Maleki *et al.*, 2017). Essential and non-essential HMs, when present in high concentrations, give rise to critical diseases in all living beings. The chief toxic HMs released from industries are copper, zinc, chromium, lead, nickel, arsenic, mercury, and cadmium (Mehdipour *et al.*, 2015). These HMs are derived from the combustion of fuel, industrial effluents such as stain and fabric production, laminating debris, cycles and supplementary segments, welding and excavation operations, metal plating, waste matter treatment plants, chemical fertilizers, and garbage dumps (Zeng *et al.*, 2017) and affect water and soil ecosystem. The uptake of HMs by plants depends on environmental factors such as pH of the soil and organic matter, metal relevance, water, air, and plant species (Shen *et al.*, 2017). The solubility of HMs elevates under oxidizing environment (\downarrow pH) because of their ionic configuration, while in a reducing environment (\uparrow pH), their distribution declines due to less solubility (Lena and Rao, 1997). In plants, toxicity is associated with the decrease in photosynthesis, nutrient assimilation, root damage, and, ultimately, plant death (Ali *et al.*, 2011; Gill *et al.*, 2015; Zaheer *et al.*, 2015). Different HMs have different sites of action within the plant due to differences in their solubility, transport, and chemical reactivity. HMs are highly reactive due to variable oxidation states and cause toxicity at the cellular and molecular levels. HMs bind firmly to oxygen, nitrogen, and sulfur atoms (Nieboer and Richardson, 1980) due to free enthalpy of the product and retard functions of necessary elements in biological molecules, including pigments and enzymes (Ali *et al.*, 2013) by binding with cysteine residues of enzymes, which inhibits soil enzyme activity or sulfhydryl groups of structural proteins (Hall, 2002). They also arrest functional groups of main cellular molecules (Hossain *et al.*, 2012). HMs stress results in nutrient deficiency, oxidative stress, metabolic agitation, and genetic disorders in plants. A

higher concentration of HMs stimulates the formation of excess methylglyoxal, free radicals (O_2^- and OH^-), and reactive oxygen species (Hossain *et al.*, 2012; Sytar *et al.*, 2013). So, to survive against these harmful metals, plants have developed intricate methods to regulate the absorption and aggregation of metals. There are different procedures of metal tolerance in plants, the general mechanism involved in different HMs tolerance is described in Fig. 1.

CHROMIUM TOXICITY IN HIGHER PLANTS

Chromium is a nonessential toxic HM possessing no role in plant metabolism (Hussain *et al.*, 2018). It is the 21st most common element in the earth's crust (Ertani *et al.*, 2017). The agency for toxic substances and disease registry and the international agency for research on cancer (ATSDR and IARC) have declared it the first cancer-causing agent and positioned it as seventh out of twenty top dangerous substances (oh *et al.*, 2007; Brasili *et al.*, 2020). The source of chromium pollutants on earth is mainly anthropogenic activities like tanning, smelting, mining, textile dyes, pigments, ceramic glazes, refractory bricks, utilization of inorganic manures, insecticides, etc. (Fig. 2) (Tseng *et al.*, 2019; Sanjay *et al.*, 2020).

Both the Cr oxidation states (Cr^{3+} and Cr^{6+}) show different chemical effects, toxicity, translocation, and climatic response (Choppala *et al.*, 2018). Cr^{6+} is reported as more dangerous due to greater solubility, carcinogenicity, mobility, and oxidizer of cellular components resulting in low yield of plants (Ertani *et al.*, 2017; Singh and Prasad, 2019). The transformation and absorption of Cr in plants are regulated by its oxidation number, concentration, soil pH, and plant species (Babula *et al.*, 2008; Gomes *et al.*, 2017). Gill *et al.* (2016) revealed that *B. napus*, cultivar ZS 758, had a powerful metabolism and was more resistant to Cr toxicity. The toxicity of Cr for crops in the nutrient solution is about 0.5–5.0 mg mL^{-1} , while for soil, 5-100 mg/g and 0.1 to 117 $\mu\text{g L}^{-1}$ in fresh water. Plants cannot uptake Cr directly from the soil (Singh *et al.*, 2013), so its uptake occurs along the water and essential metal carriers such as Fe, S, and P

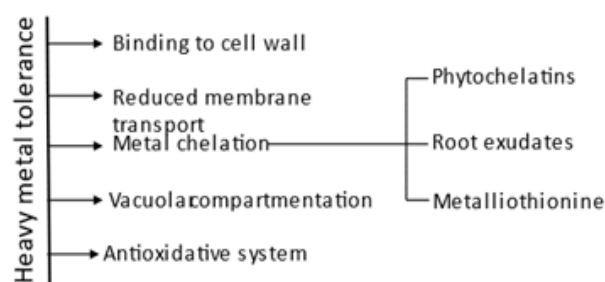


Fig. 1. General mechanism involved in different HMs tolerance (Kumar *et al.*, 2016)

due to structural similarity (Farid *et al.*, 2017; Shahid *et al.*, 2017; Zhao *et al.*, 2019). Cr stress causes Fe and N deficiency by inhibiting the plant's root Fe³⁺ reductase (Barton *et al.*, 2000), nitrate reductase (Zou *et al.*, 2009), and nitrogenase enzymes (Sessitsch *et al.*, 2002). The symptoms of Cr injury in plants are limiting in plant growth or biomass (Danish *et al.*, 2019), necrosis and chlorosis (Gupta *et al.*, 2017), seed germination (Sultana *et al.*, 2020), and wilting, etc. (Ahmad *et al.*, 2020). However, such symptoms are not uniform, even in cultivars of the same plant. E.g., according to Gill *et al.* (2014), Zheda 622 was more sensitive to Cr than ZS 758, Zheda 619, and Zy 50 cultivars in *B. napus*. As chromium stress increases in plants, some changes in the shape and size of cellular organelles occur. In leaves of *B. napus* during Cr stress, an increase in size and quantity of starch grains, plastoglobuli, damaged thylakoid membranes, immature nucleoli, and mitochondria were observed, while roots showed enlarged vacuoles, damaged cell walls, and cell membranes, an increased number of mitochondria and size of the nucleolus as well as plasmolysis (Gill *et al.*, 2014).

Cr toxicity has been manifested to cause decreased H⁺ ATPase function of cell membrane because of its binding capability with essential metal carrier channels (Sahid *et al.*, 2017). The Cr⁺⁶ form alters membrane function by oxidizing the membrane biomolecules, which triggers oxidative degradation of lipids (Shahid *et al.*, 2017; Sharma *et al.*, 2020) and disturbs chloroplast structure by degradation of enzyme - delta-aminolaevulinic acid dehydratase (Dey and Paul, 2016). A new Cr-responsive protein (CL2535.Contig1 All) was observed in *Brassica napus* during the Cr toxicity study (Gill *et al.*, 2016).

Chromium mobilization, uptake, and transport

The biological availability of metals depends on their solubility and binding capacities to soil particles (Cristaldi *et al.*, 2017). Acidification of rhizosphere and root exudates such as malate, citrate, amino acids, etc., increase metal aggregation in plant roots (Kaur *et al.*, 2018; Khanna *et al.*, 2019). The uptake of Cr from the soil in plants depends upon plant species, types of root secretion, the surface area of the root (Ertani *et al.*, 2017), soil pH, salinity, soil electrical conductivity (Islam *et al.*, 2016), availability of soluble salts, soil redox potential, the quantity of organized material, temperature and the concentration of Cr and its oxidation state (Boechat *et al.*, 2016; Gomes *et al.*, 2017; Shen *et al.*, 2017). Metal aggregation becomes low at high soil pH due to the complex formation with organic matter and oxides. Microorganisms also have prominent effects on metals because they secrete metabolites that bind with metals to enhance their translocation in the rhizosphere of plants (Chen *et al.*, 2014). Cr is a non-essential toxic HM with no specified transporter for its absorption in plants (Singh *et al.*, 2013). Its uptake occurs with water and essential elements. The plant roots can absorb both forms of Cr (Cr⁺³ and Cr⁺⁶). The uptake of Cr (III) is a passive process occurring at the cation inter-change spot of the cell wall without energy requirement (Shanker *et al.*, 2005; Babula *et al.*, 2008), while absorption of Cr (VI) occurs actively through plasma membrane carriers of essential elements such as sulfate (Singh *et al.*, 2013; Shahid *et al.*, 2017; Singh and Prasad, 2019). Cr also interferes with the uptake of Fe, S, N, K, Mg, Na, Ca, Zn, Mn, and P (Gomes *et al.*, 2017; Zhao *et al.*, 2019). Zaheer *et al.* (2019) reported that Cr toxicity causes decreased ac-

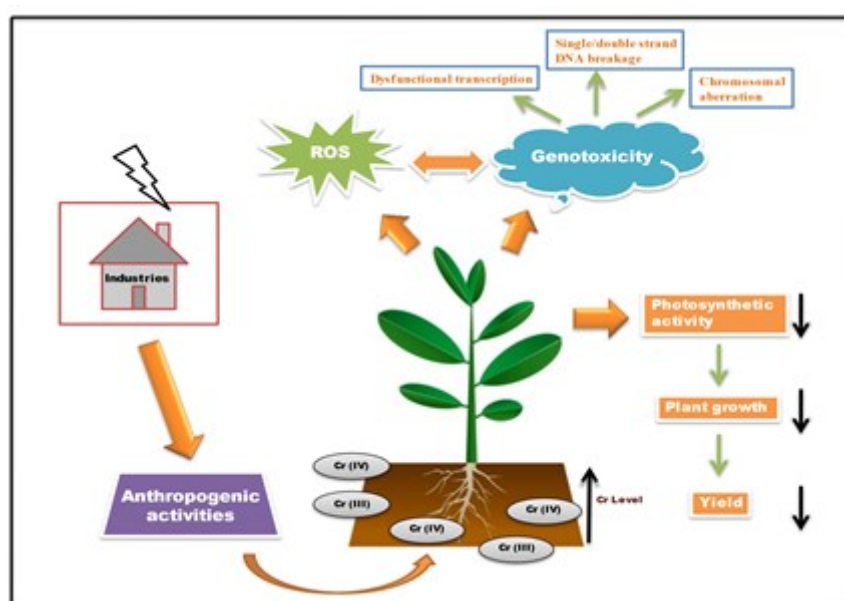


Fig. 2. Source of chromium and its entry into plants (Singh *et al.*, 2013)

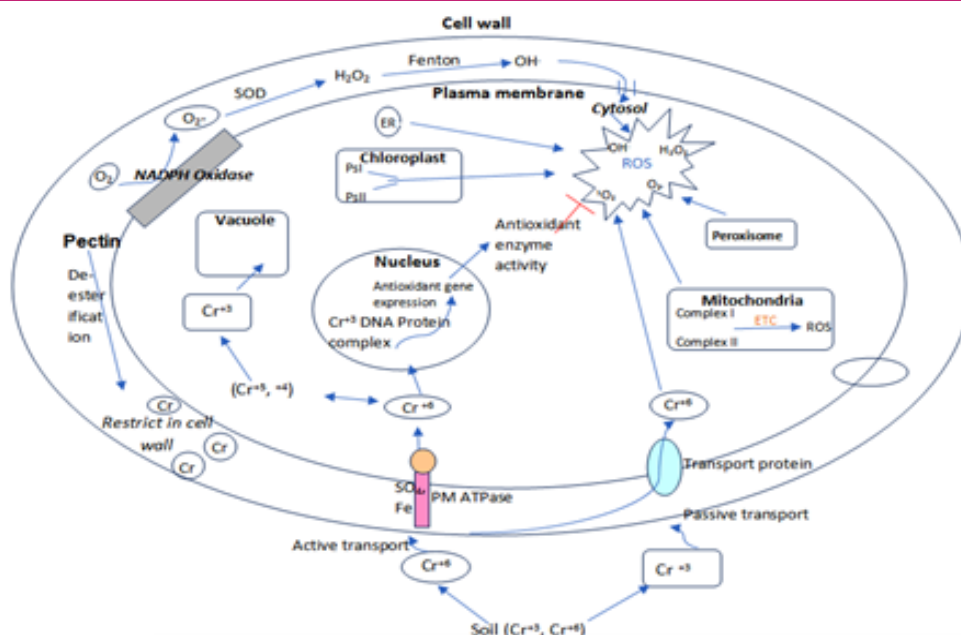


Fig. 3. Chromium uptake and its toxicity in plants (Shanker et al., 2005)

accumulation of Zn in all portions of *Spinacia oleracea* L. plant. The transformation ratio of Cr^{3+} and Cr^{6+} from roots to shoots is also different. Skeffington et al. (1976) noticed that extra Cr was transferred from roots to shoots when Cr^{6+} treatment was given instead of Cr^{3+} . Cr can undergo an oxidoreduction reaction spontaneously in different earth circumstances (Shahid et al., 2017). Wei et al. (2016) described that organic carbon matter reduces Cr (VI) to Cr (III). The chromium uptake mechanism and toxicity are shown below (Fig. 3).

After absorption by root hairs or binding to the cell wall, Cr is transported mostly through the plant xylem (Hayat et al., 2012). When Cr^{6+} moves across the endoderm via symplast, it is reduced to Cr^{3+} by root reductases and accumulates in root apoplast or vacuoles of root cortex cells (Shanker et al., 2005; Hayat et al., 2012), or it is transported through the xylem by symplastic system distributed in the cytoplasm of cortical cells (Mongkhonsin et al., 2011). After uptake into the root symplast, further movement of metals into the xylem occurs through three stages: segregation of metals in root cells, simplistic transfer towards stele, and delivery within the xylem. Basically, the maximum Cr in plants is accumulated in the root system, followed by stems, leaves, and seeds (Tiwari et al., 2009). Ahmad et al. (2020) reported that *Brassica oleracea* L. germinated during Cr (VI) treatment demonstrated the highest aggregation of Cr in roots and least in flowers. The passage of metals in the xylem from the root to the stem mostly occurs along with transpiration, which creates a tension for the movement of water and solutes upwards (Taiz and Zeiger, 2002). In the leaves, metals are transferred along with membrane transport proteins.

Roots are the first plant organs to contact Cr, affecting them more than shoots (Zhao et al., 2019). At low Cr^{6+} concentration, the root showed more injury because Cr^{6+} has significant potential to penetrate the plant-root system and cross the endodermis via symplast for reduction and retention in the root cortex cells (Shanker et al., 2005). The apoplast of the root cortex is freely permeable for solutes, but further on, the endodermal layer of the cell wall serves as an obstacle for apoplastic diffusion.

Oxidative stress and ROS generation by chromium

Plants are immobile, so they are susceptible to various environmental stress like drought, HMs, temperature, salinity, etc. Stress conditions can interrupt plants' ROS equilibrium (Zaheer et al., 2019; Saleem et al., 2020c). The production of ROS such as superoxide free radicals ($\text{O}_2^{\cdot-}$), hydroxyl radicals (OH^{\cdot}), hydroperoxyl radicals (HOO^{\cdot}), the paramagnetic singlet oxygen ($^1\text{O}_2$), nitrogen oxide radical (NO), hydrogen peroxide (H_2O_2), hypochlorous acid (HOCl) segments (Turkan et al., 2018) and cytotoxic compounds like methyl glyoxal (MG) is an unavoidable effect of metal toxicity in plants (Singh et al., 2016; Singh and Prasad, 2019). ROS result from metabolic pathways like photosynthesis and respiration and are produced in plant organelles such as chloroplast, mitochondria, peroxisomes, glyoxysome, and cytosol (Chen et al., 2017; Abbas et al., 2018). Cr directs excess ROS in plants by interfering with NADPH oxidases (plasma membrane) and the electron transport chains, which develop electrons leakage to an oxygen molecule (Singh and Prasad, 2019; Smirnov and Arnaud, 2019). In plants, the concentration-dependent dual function of ROS is known. When

present at the basal level, they act as signalling molecules and manage the plant growth process (Mittler, 2017; Waszczak *et al.*, 2018). The higher level of ROS triggers the destruction of macromolecules and a decline in plant growth (Qi *et al.*, 2019). The basal level of ROS is attained during the non-stress condition by equilibrium and a complicated antioxidant enzymatic/non-enzymatic support system (Shahid *et al.*, 2014; Kushwaha *et al.*, 2019). The vital antioxidant enzymes are superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), ascorbate peroxidase (APX), glutathione reductase (GR), glutathione peroxidase (GPX), single dehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR) and glutathione S-transferase (GST) (Kabir, 2016). Saleem *et al.* (2020d) and Mallhi *et al.* (2019) reported dual action of antioxidant enzymes in *Hibiscus cannabinus* L. and castor bean, respectively: minimal metal tension enhances the antioxidant enzyme activities, whereas elevated metal tension diminishes the action of antioxidant enzymes. During high-stress conditions, equilibrium is not maintained between the ROS formation and anti-oxidative systems, which causes oxidative stress and, finally, the destruction of the plant (Sharma *et al.*, 2012; Xie *et al.*, 2019). The response of antioxidant enzymes depends not only on the level of Cr supplied but also on plant species and their developmental phase. Pandey *et al.* (2005) observed that in *B. juncea* during Cr⁶⁺ treatment, SOD action diminished and APX action elevated in root and leaves parts of the plant (under 5 days of disclosure) but reduced later (15 days of disclosure). Catalase action remained unaffected in the roots but elevated in the leaves, while GR action was also elevated in both leaves and roots.

Although ROS has harmful effects on the plant system, sometimes it also acts as a signaling molecule.

Smirnov and Arnaud (2019) reported that H₂O₂ act as a signaling molecule when present in a low amount and evoke signal transduction in plant tissues during metal stress. The H₂O₂ activates a cascade of signals (Van Breusegem *et al.*, 2008) that create ROS surge within the cells, transferred and stored in various parts (Mittler *et al.*, 2011). Yildiz *et al.* (2013) showed that in *B. napus*, H₂O₂ contributes to Cr tolerance by ameliorating antioxidant enzymes action, chlorophyll, thiol content, stimulation of metallothionein protein (BnMP1), and reduced oxidative degradation of lipids. The overview of oxidative stress generated through Cr toxicity is given in Fig. 4. Redox-active metals such as Cr, Cu, and Fe induce oxidative stress in plants through Haber–Weiss, and Fenton reactions, which significantly promote ROS and interrupt the equilibrium among prooxidant and antioxidant proportions. These metals have an unpaired electron in their orbitals, enabling them to accept or donate a single electron. This electron can be transferred to the ground state oxygen molecule and thus generate ROS (Hourri *et al.*, 2020). Chromium produced oxidative stress (Sharma *et al.*, 2019; Kushwaha and Singh, 2020; Wakeel *et al.*, 2020) via Haber–Weiss cycle and Fenton reactions like other heavy metals such as Cd and Pb, which reduce glutathione pool and increase prooxidant response. Different reports of the oxidative response to Cr stress revealed in higher plants are listed in Table 1.

Yildiz *et al.* (2013) studied the participation of H₂O₂ in the signalling process, due to which the expression level of antioxidant enzymes SOD, CAT, APX, and POD varied in *B. napus* plant under different Cr concentrations. Cr treatment increased lipid peroxidation in *Vigna radiata* (Gautam *et al.*, 2020), *B. oleracea* (Ahmad *et al.*, 2020), Maize (Anjum *et al.*, 2017), and *H. annuus* (Farid *et al.*, 2020). SOD, APX, CAT, and GR

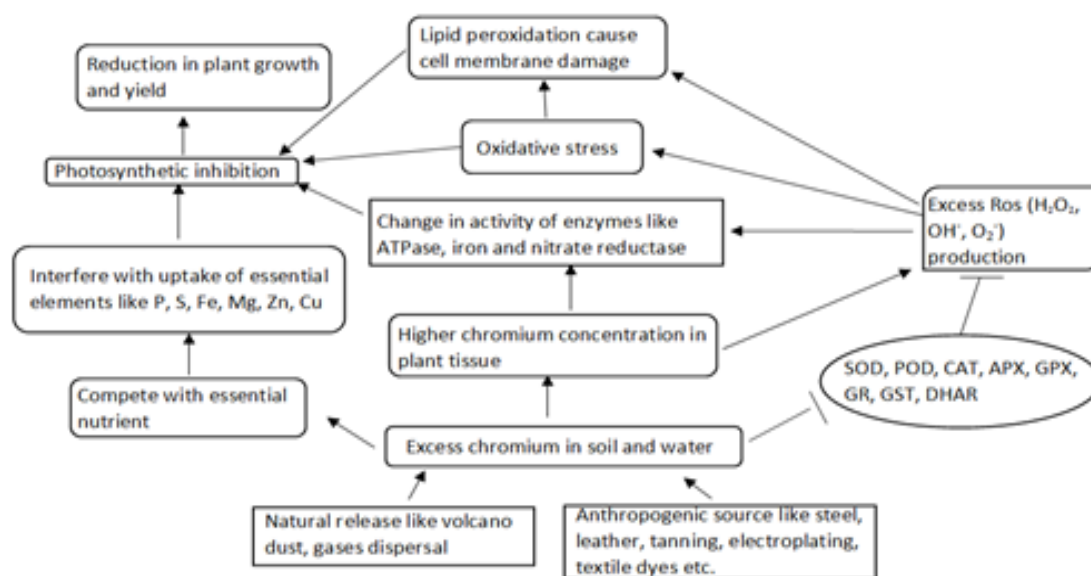


Fig. 4. Oxidative stress generated through Cr toxicity (Sharma *et al.*, 2020)

activities vary according to Cr concentration and plant species (Yilmaz et al., 2017; Kushwaha and Singh, 2020). In *B. napus* and *G. max*, Cr increased glutathione content while activities of antioxidative enzyme SOD, APX, CAT, and GR increased or decreased according to Cr concentration and growth stage of the plant (Zaheer et al., 2020). In leaves and roots of *H. annuus* and *B. oleracea*, 10 mg/100µM Cr concentration increased the action of antioxidants CAT, SOD, APX, and POD, whereas enzymatic activities were suppressed at 20 mg/200 µM (Ahmad et al., 2020; Farid et al., 2020). Rai et al. (2004) and Gautam et al. (2020) reported that during Cr stress, protein content diminished while antioxidant enzymatic activities (SOD, GPX, and CAT), polyphenol content enhanced in *Ocimum tenuiflorum* and *V. radiata* plants, respectively. In *T. aestivum*, antioxidative enzyme activities (SOD, POD, CAT, and APX) in leaves and roots were decreased with increasing concentration (between 25 and 100 mg/kg) of Cr (Seleiman et al., 2020). Mallhi et al. (2020) reported that Cr stress generated oxidative injury in the leaves and roots of *H. annuus* plants due to the production of H₂O₂. During Cr treatment, the action of SOD and CAT increased in both roots and leaves, while GST activity was inhibited in *P. sativum*, *S. Lycopersicon*, and *S. melongena* (Kushwaha and Singh, 2020). Several experiments have been done under

various stresses that clearly show the potential role of aminolevulinic acid in combating oxidative stress. Gill et al. (2015) administered 5-aminolevulinic acid to find lessened oxidative stress in *Brassica napus* (ZS 758, Zheda 622) under Cr stress by promoting antioxidant enzyme activities (SOD, POD, CAT, APX, GR) and the expression of their associated genes. Gene's transcript levels were amplified by 77,76,177, 63 and 51 % in cultivar ZS 758 and 37, 25, 113, 47 and 22% in Zheda 622, respectively. The ALA is the ordinary ancestor of tetrapyrroles and helps in the growth regulation of plants. It has a role in photosynthesis and is well known for conserving plant development, cell turgidity, enhancing ALA content, and diminishing Cr concentration (Gill et al., 2015). Gill et al. (2016) demonstrated that plant hormone salicylic acid could increase tolerance in *B. napus* to Cr stress via enhancing the reactive oxygen scavenging by promoting enzymatic antioxidant activities, related gene expression, secondary metabolism, and cell structural alterations and transcript levels of particular stress-related proteins. Chromium and other related HMs cause significant damage to cellular organelles, mainly endomembrane, chloroplast, and mitochondria, as transport occurs across these membranes. Cr disrupts the organelles of plant cells by enhancing the size of starch grains and the number of plastoglobuli, causing damage to the chloroplast and

Table 1. Reports of the oxidative reaction to Cr stress revealed in higher plants

Chromium concentration	Exposure time (days)	Plant species	Antioxidant enzymes modified	References
100 µM	21	<i>Solanum lycopersicum</i> L.	SOD, CAT, APX, GR, GST, GS, γ-GCS	Alamri et al., (2020)
0, 25,50,100 mg/kg	90	<i>Basella alba</i> L.	POD, SOD, CAT	Zewail et al., (2020)
5, 10, 20 mg/kg	56	<i>Helianthus annuus</i> L.	POD, SOD, CAT, APX	Farid et al., (2020)
0, 10, 100, 200 µM	28	<i>B. oleracea</i> L.	SOD, CAT, POD	Ahmad et al., (2020)
30, 60, 90, 120, 150 µMol L ⁻¹	110	<i>Zea mays</i> L.	SOD, POD, CAT, APX, GPX, GR	Anjum et al., (2017)
0, 2, 8, 16 mg/ L	3	<i>Oryza sativa</i> L.	SOD, CAT, POD, APX, GR, GPX, MDHAR, DHAR	Fan et al., (2020)
25 µM	7	<i>S. lycopersicum</i> L., <i>Pisum sativum</i> L. and <i>Solanum melongena</i> L.	SOD, CAT, GST	Kushwaha and Singh, (2020)
250 µM	7	<i>Vigna radiata</i>	POD, CAT, SOD, GR, APX, DHAR, PPO, GST and GPX	Gautam et al., (2020)
250 µM	17	<i>Ricinus communis</i> L.	POD, SOD, CAT, APX	Qureshi et al., (2020)
0, 25, 50, 100 mg/L	80	<i>T. aestivum</i> L.	CAT, APX, SOD, POD	Seleiman et al., (2020)
100 µg	21	<i>S. lycopersicum</i> L. and <i>S. melongena</i> L.	SOD, CAT, GST	Singh et al., (2020)

SOD- Superoxide dismutase, **CAT-** Catalase, **APX-** Ascorbate peroxidase, **POD-** Peroxidase, **GST-** Glutathione S-transferase, **GR-** Glutathione reductase, **PPO-** Polyphenol oxidase, **DHAR-** Dehydro-ascorbate reductase, **MDHAR-** Mono dehydro-ascorbate reductase, **GPX-** Glutathione peroxidase, **GS-** Glutathione synthetase, **γ-GCS-** γ-Glutamyl cysteine synthetase, **mg-** Milligram, **kg-** Kilogram, **µM-** Micromolar, **µg-** Microgram, **L-** Liter

Table 2. List of some Cr hyperaccumulator plants

Plant species	Metal	Family	Bioaccumulation	References
<i>Zea mays</i> L.	Cr	Poaceae	2538 mg/kg	Naseem et al. (2015)
<i>Nymphaea spontanea</i>	Cr	Nymphaeaceae	2,200 mg/kg	Choo et al. (2006)
<i>Pteris vittate</i>	Cr	Pteridaceae	5717 mg/kg	Wang et al. (2012)
<i>Salvinia natans</i>	Cr	Salviniaceae	5,200 mg/kg	Dhir et al. (2009)
<i>Nopalea cochenillifera</i>	Cr	Cactusaceae	25263 mg/kg	Adki et al. (2013)
<i>Brassica napus</i>	Cr	Brassicaceae	306.1 mg/Kg	Brunetti et al. (2011)
<i>Prosopis juliflora</i>	Cr	Fabaceae	372.13 mg/kg	Shukla et al. (2011)
<i>Thlaspi caerulescens</i>	Cr	Brassicaceae	3,400 mg/kg	Shahandeh and Hossner (2000)
<i>Urtica dioica</i>	Cr	Urticaceae	12–20 mg/Kg	Shams et al. (2010)
<i>Gynura pseudochina</i>	Cr	Asteraceae	1,611 mg/Kg	Mongkhonsin et al. (2011)
<i>Baccharis sarothroides</i> A. Gray	Cr	Asteraceae	162.6 mg/Kg	Haque et al. (2008)
<i>Helianthus annuus</i> L.	Cr	Asteraceae	1,356 mg/kg	Ranieri et al. (2013)
<i>Salix babylonica</i> L.	Cr	Salicaceae	1,278.96 mg/kg	Yu et al. (2008)
<i>Brassica juncea</i>	Cr	Brassicaceae	1,640 mg/kg	Diwan et al. (2010)
<i>Allium griffithianum</i>	Cr	Amaryllidaceae	568.33 mg/kg	Sajad et al. (2020)
<i>Azolla pinnata</i>	Cr	Salviniaceae	5000-15000 mg/kg	Arora et al. (2006)
<i>Solanum viarum</i>	Cr	Solanaceae	382 mg/kg	Afonso et al. (2019)
<i>Origanum vulgare</i> L.	Cr	Lamiaceae	1200 mg/kg	Levizou et al. (2018)
<i>Vernonia cinerea</i> (L.) Less.	Cr	Asteraceae	5500 mg/kg	Mohanty and Patra (2020)
<i>Phragmites australis</i>	Cr	Poaceae	4285 mg/kg	Calheiros et al. (2008)
<i>Prosopis laevigata</i>	Cr	Fabaceae	8090 mg/kg	Buendía-González et al. (2010)
<i>Spartina argentinensis</i>	Cr	Poaceae	15.1 mg/g	Redondo-Gómez et al. (2011)
<i>Convolvulus arvensis</i> L.	Cr	Convolvulaceae	2800 mg /kg	Gardea-Torresdey et al. (2004)
<i>Leersia hexandra</i>	Cr	Poaceae	1844 mg/kg	Liu et al. (2011)

mitochondrion structures (Gill et al., 2016).

Chromium accumulation and detoxification

The accumulation of metal in plants depends upon its uptake capacity, intracellular binding sites, concentration, the affinity of the chelating agent, and translocation activities (Lopez Luna et al., 2009). Cr accumulates in the root by binding with the cell wall through functional groups like amino, phosphate, thiol, carboxyl, etc. (Eggs et al., 2012) and immobilization in vacuoles (Sinha et al., 2018) or root exudates (malic acid, amino acid) (Kaur et al., 2018; Khanna et al., 2019). Sobariu et al. (2017) described that *Lepidium sativum* accumulates Cr in the roots due to ion immobilization in vacuoles. Chromium accumulation in plants has effects on gene functions too. Gill et al. (2017) found that Cr stress increased the expressions of BnaA08g16610D, BnaCnng 19320D, and BnaA08g00390D genes in *B. napus*. These genes encoded proteins that bound nucleic acid and transition metal ions and protein kinase and phosphotransferase activities.

Plant microbes' interactions in Cr metabolism

Plant growth-promoting rhizobacteria (PGPR) are the plant integrated free-living, earth-born bacteria that se-

crete distinct metabolites such as organic acids, siderophores (main metal chelating agents), exopolysaccharide (EPS), hydrogen cyanide (HCN), biosurfactants, antibiotics and amplify the plant growth by minimizing the plant injury induced by living (microorganisms generated injury) and non-living (HM caused plant injury) components. These metabolic compounds can switch the mobility (chelation, precipitation, immobilization), the ionic position of metals including Cr, Fe, Hg, Se, and Mn (acidification, oxidation), and change the injurious dynamic configuration into a non-injurious static configuration (Ma et al., 2011). These increase the plants' phyto-remediation, phyto-stabilization, and phyto-volatilization capabilities (Ahemad, 2019). Microorganism inoculations can impart an alternative method of removing HMs from the soil. Karthik et al. (2017) revealed that inoculation by rhizobacteria *Serratia* (Srivastava and Thakur 2012) helped in the reduction and immobilization (decrease mobility and toxicity) of Cr (VI) by intricate methods such as ion-exchange, complexation, and coprecipitation. These rhizobacteria are established around the plant by the leakage of plant chemicals, amino acids, proteins, and antibiotics to cause a reduction of HMs toxicity. PGPR can be categorized, depending on their

utility like biofertilizers (expand the soil-nutrient accessibility), Phyto-stimulators (trigger plant development by making plant hormones), rhizo-remediators (regulate the waste material proximity via metal dilution) and bi-pesticides (manage plant pathogen and infection by the emission of lysing agent and biochemical compounds) (Ahemad, 2019) and depends on inherent distinctiveness as root colonizer, assist plant growth, adjust, persist and challenge with other microbial foliage. PGPR stimulates plant growth in different ways, i.e., accelerates the soil-nutrient accessibility, triggers root development, cytokinesis along with expansion and metabolic counteraction, arrests HMs induced phytotoxicity, or enhances the induction of systemic resistance. They also prevent oxidative damage by producing different antioxidants and maintaining ROS proportion in plants (Karthik et al., 2016). The Cr stress in *B. napus* activated a wide range of metabolic pathways, including vitamin B₆, tryptophan, sulfur, nitrogen metabolism, zeatin biosynthesis, and linoleic acid production, proline, aspartate, and glutamate (Gill et al., 2016).

Cr modifies microbial diversity through different methods involving microbial biomass reduction, falling off particular microbial populations, and switching the microbial diversity layout. Inoculation of microbes in soil (e.g., arbuscular mycorrhiza and rhizospheric microbes) increases the hyper-accumulator plant remediation ability by translocating heavy metal from root to aerial parts (Rajkumar et al., 2010; Ma et al., 2011). Sheng et al. (2008) revealed that inoculation of *Bacillus* sp. elevated Cd uptake in plant tissue while *P. aeruginosa* boosted the uptake of Cr and Pb in maize plants (Braud et al., 2009). These microbes increase the bio-remediation capacity of the plants and accelerate the tolerance limit of metal toxicity via nutrient recycling, conservation of earth layout, and managing infection. They have the capability to uptake the metal (Cr) by different methods, including adsorption, bioconversion, bio-sorption, bio-accumulation, biomineralization, precipitation, complexation, alkalization, bio volatilization, bio-leaching, and decomposition that assist the plants in mitigating their cytotoxicity (Karthik and Arulselvi, 2017). Moreover, Gill et al. (2016) discovered that Cr inhibits KEGG pathways in *B. napus*, including stilbenoid, diarylheptanoid, gingerol production, limonene, and pentose degradation as well as glutathione metabolism in ZS 758, while ribosome and glucosinolate biosynthesis in Zheda-622. Rhizobium inoculations also increase the glutathione reductase action in *P. sativum* during Ni and Zn treatment (Wani et al., 2008). Anjana et al. (2007) reported that *Nostoc calcicole* and *Chroococcus* were effective Cr (VI) eliminators by biosorption. In certain microbes, bio-sorption and bio-accumulation impart resistance to Cr⁶⁺. Flores-Alvarez

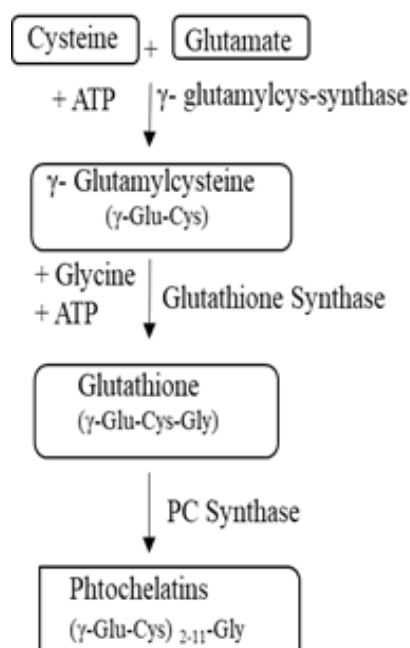


Fig. 5. Biosynthesis of PCs in plants (Sharma et al., 2016)

et al. (2012) showed that in *Neurospora crassa*, Cr⁶⁺ assembled in the vacuolar complex to increase its resistance. Different microbes like fungi, bacteria, algae, and actinomycetes reduce Cr⁶⁺ by various enzymatic and non-enzymatic methods (by vitamin C, H₂S, cysteine, mercapto groups, and GSH) (Viti et al., 2014; Joutey et al., 2015). Some membrane enzymes of microbes also help reduce Cr (VI) (Joutey et al., 2015; Xia et al., 2018). For example: in *Thermus scotoductus*, dihydrolipoamide dehydrogenase acts as a Cr⁶⁺ reducer with the help of NADPH (electron donor). The over-expression of certain microbial genes can expand the Cr⁶⁺ consumption power of plants. Cytokinin β-glucosidase genes of *Agrobacterium tumefaciens* over-expressed in *Nicotiana glauca* while glutathione synthetase gene *gshI* of *E. coli* in *B. juncea* plant assimilated extra Cr (VI) as compared to wild counterparts (Del Bubba et al., 2013; Malandrino et al., 2017).

Cell wall and plasma membrane in Cr interaction

The cell wall is the first anatomical barrier protecting plants against biotic and abiotic stresses (Scheller and Ulvskov, 2010; Tucker and Koltunow, 2014). Environmental abiotic stresses modify the structure and composition of the cell wall (Berni et al., 2019), and mainly the root system is affected due to direct contact with contaminated soil. The plant cell wall consists of polysaccharides (cellulose microfibrils, pectin, and hemicelluloses), proteins (Somerville et al. 2004), and phenolics which bind with HMs and store them in the cell wall (Krzeslowska, 2011; Vuletic et al., 2014). The binding affinity of Cr ions depends on the number of functional groups (–COOH, –OH, and –SH) existing in the cell

wall (Pelloux *et al.*, 2007). The cell wall structure also influences the translocation within the xylem. The first living structure called 'plasma membrane' is also affected by Cr toxicity due to the production of free radicals (ROS), which degrade the cellular components such as lipid peroxidation of unsaturated fatty acids (residues of phospholipids) and oxidation of proteins (Schutzendubel and Polle, 2002). These damages change the structure, functions, and mobility of the membrane, which results in the imbalance of membrane-binding enzymes in the cell and disturb the cell metabolism process (Yadav, 2010). The plasma membrane also helps Cr tolerance by reducing their uptake or increasing metal efflux ions.

Chromium sequestration in plant cell

Plants have various methods at the cellular level, which are concerned with detoxification and help in tolerance to HMs stress (Hall, 2002). The accumulation of metal in plants depends upon its uptake capacity, intracellular binding sites, concentration, the affinity of the chelating agent, and translocation activities (Lopez Luna *et al.*, 2009). The addition of chelating agents can amplify the absorption of Cr by the plants and trigger the metal absorption capability of the microbial population throughout the plant rhizosphere. Chelates enhance the metal tolerance and deposition in non-hyperaccumulator plants, including *Ricinus communis* L. (Zhang *et al.*, 2016). When chelating agents like ethylene diamine tetra acetic acid and citric acid are added to the earth, the solubility of metal increases because of the establishment of an aqueous dissolved metal network with the chelating agent. Organic chelates also ameliorate the availability of essential elements (Fe, S, P, Mg, Ca), which competes with Cr uptake (Bloem *et al.*, 2017). Metallothioneins and phytochelatin (PCs) are two main classes of metal-binding proteins observed throughout the plant kingdom. Overall, the sequestration of Cr in organisms includes an attachment with cytosolic cysteine-rich MTs (Metallothionein's) polypeptides along with sequestration (Sacky *et al.*, 2014). These peptides are enzymatically derived and synthesized when a cell is exposed to stress conditions. Their main role is to promote metal purification and equilibrium of vital micronutrients (Kneer and Zenk, 1992). PCs are small cysteine-rich, non-protein heavy-metal binding peptides, having a general structure $(\text{Glu-Cys})_n \text{X}$, where X is Gly, γ -Ala, Ser or Glu ($n = 2-11$, based on living being) (Gupta *et al.*, 2013; Shukla *et al.*, 2013). Apart from the main PC families, different plant species have other groups of PCs like homo-phytochelatin $(\text{Glu-Cys})_n\text{-Ala}$ or iso-phytochelatin $(\text{Glu-Cys})_n\text{-Glx}$. The chain length of PCs varies with plant species and metal type. Piechalak *et al.* (2002) reported in legumes that PCs with longer chains have a strong binding ca-

capacity to Pb as compared to those with shorter chains. The synthesis of PCs in plants takes place under different stresses like heat, salinity, UV-B, herbicides, and HMs (Cr, Cd, As, Pb, etc.) toxicity through enzymes such as PC synthase (Clemens, 2006; Emamverdian *et al.*, 2015) by glutathione and its homologs act as substrates (Zagorchev *et al.*, 2013). Cr bind with the enzyme γ -glutamylcysteinyl dipeptidyl transpeptidase (PC synthase) and activate it to assemble the transformation of GSH to PCs (Gharieb and Gadd, 2004). GSH is manufactured from its constituent amino acids in two steps, first, γ -ECS (γ -glutamylCys synthetase) joins Glu with Cys, and then GSH synthetase adds Gly to γ -EC. The mechanism of biosynthesis of PCs in plants is detailed in Fig. 5. The synthesis of PCs occurs by reducing the GSH pool in roots, aerial parts (Rausser *et al.*, 1991), and tissue cultures (Schneider and Bergmann, 1995). GSH, a thiol molecule, promotes the plant against metal stress (Cr, Cd, As, etc.) by activating signal transduction pathways. Gill *et al.* (2017) discovered that Cr stress, along with GSH treatment, enhances the expression of genes encoding protein kinases like BnaCnng69940D and BnaC08g49360D that were involved in protein kinase activity, signal transduction, and oxidoreductase activity. Some genes also govern the transport over the cell membrane. But most of the research proposed that PCs are initially synthesized in roots. The induction of PCs coupled with the antioxidant defense system in response to Cr stress suggested the combined role of PCs and antioxidants in conferring tolerance to accumulated Cr in *B. juncea* and, therefore, the plant's aptitude as a possible Cr remediator (Diwan *et al.*, 2010). In *V. radiata*, there was lesser induction of PCs at high Cr concentration, which may be due to its transport to shooting or because PCs might have degraded due to excessive Cr accumulation (Harmens *et al.*, 1993).

Yurekli and Kucukbay (2003) observed that in *H. annuus* during Cd stress, PCs extent in roots was greater than in leaves. Fidalgo *et al.* (2013) observed that in *Solanum nigrum* L., the productivity of PCs was increased in roots under copper stress which involved binding of excess Cu in the root and preventing its movement towards the shoot. Huda *et al.* (2017) observed that the accumulation of phytochelatin and the OsPCS1 (phytochelatin synthase) genes were highly stimulated by the combined treatment of Si and Cr compared to Cr-stressed plants. Similarly, Mukta *et al.* (2019) revealed that calcium-mediated inhibition of Cr translocation from root to shoot in rice seedlings, suggesting increased accumulation of phytochelatin binding Cr for vacuolar sequestration in roots. OsPCS1 (phytochelatin synthase), OsMT1 (metallothionein), and OsHMA3 (P-type ATPase 3) transcripts were considerably upregulated following SA supplementation under

Cr stress, indicating that these chelating agents may bind to Cr to increase its retention in roots (Huda et al., 2016). Heiss et al. (2003) signified that long-duration treatment of Cd in *B. juncea* resulted in greater aggregation of PCs in leaves than roots. In plants, PCs production, accumulation and movement depend upon the capacity of plant species to tolerate metal toxicity. Diwan et al. (2010) observed that at all doses of Cr treatment (50, 100, 150, and 200µM), PCs were considerably induced in the roots and shoots of both plants (*B. juncea* and *Vigna radiata*). Rabelo et al. (2018) showed glutathione as a substrate for metal complexing organic molecules (phytochelatin PC-SH). After attachment of metal with phytochelatin-SH, the metal system is transported by transporters such as Mg ATP-dependent carrier or ATP-binding cassette (ABC) transporter (Sytar et al., 2013) into vacuoles to convert toxic metal into nontoxic form (Song et al., 2014). Increased phytochelatin-SH during Cr treatment could be assessed as a compatible scheme of *S. lycopersicum* L. roots (Kushwaha et al., 2019). The artificial incorporation of PC genes in the transgenic plant (*Nicotiana tabacum* L.) increases their resistance to metal stress (Postrigan et al., 2012). This toxic metal sequestration procedure is considered as the main mechanism for plants to tolerate metal toxicity, including that of Cr.

Like PCs, the MTs are naturally-occurring, intracellular cysteine-rich, low-molecular-weight cytoplasmic metal-binding proteins reported in some prokaryotes, fungi, invertebrates, mammals, and in plant systems (Du et al., 2012). They were first extracted from the equine kidney (Margoshes and Vallee, 1957). Plants cannot shun abiotic stress by re-motion; plants have developed a good system of acclimation methods to survive with alters in their surroundings. The signal transduction pathways are more prominently active for these responses with mRNA levels in plants. Gill et al. (2015) studied *B. napus* (ZS 758 and Zheda 622) under Cr stress. The mRNA level of stress response proteins, including HSP90-1 and MT-1, were marked up. The mRNA accumulation takes place when abiotic stress gets started in plants. Further, Gill et al. (2017) reported that in *B. napus* during Cr stress, three MT genes (BnaA04g26560D, BnaA02g28130D, and BnaA02g01980D) were responsible for transporting water across the cell membrane. Some angiospermic plants also encode the genes like MT genes known for transportation across the membranes of cells. The genes, namely BnaC01g29930D and BnaA07g14320D, were responsible for secondary active transmembrane transporter and protein transporter activities in *B. napus* under Cr stress (Gill et al., 2017). MT gene synthesis is affected by endogenous and exogenous factors like osmotic stress, drought, HMs, temperature, nutrient deficiency, the release of different hormones, tissue senescence, injuries, viral infections, etc. (Yang and Chu, 2011; Du

et al., 2012). MTs have been grouped into four types in plants depending on their Cys arrangement (Huang and Wang, 2009). Although MTs are expressed all over the plants, different classes of MTs have been found to be expressed in an organ-specific or development stage-specific manner. Kohler et al. (2004) and Yang and Chu (2011) reported that MT 1 is mainly expressed in roots, MT 2 in shoots, MT 3 in leaves or mature fruit, while MT 4 more in growing seeds. OsMT1b carries greater biomass in roots than in shoots during Cr chelation, but OsMT2c plays a bigger role in removing H₂O₂ build-up in shoots than in roots in *Oryza sativa* (Yu et al., 2019). These findings imply that varied Cr speciation in rice tissues caused inconsistent transcriptional alterations in OsMT genes, involved in distinct regulatory and response pathways during Cr detoxification, such as metal ion chelation and ROS scavenging. Agar et al. (2020) noticed that the response of MT genes to Cr stress differed amongst different tissues. MT genes (MT2-1 and MT4) were downregulated in the shoots but increased in the roots in response to Cr stress. MT2-1 might be a useful gene resource in Cr remediation. ScMT2-1-3 overexpression in sugar cane cells in response to Cu stress shows that this gene is involved in Cu detoxification and storage (Guo et al., 2013). While Rice OsMT2b protein was discovered to exhibit ROS clearing capabilities (Wong et al., 2004). Each MT (1 to 4) is divided further and termed isoforms. Hassinen et al. (2011) observed that MT1a or MT2b is expressed in the phloem while MT2a and MT3 are in the mesophyll cells of young leaves or root tips. Memon et al. (2001) divided *Arabidopsis* MT4 into two classes, MT4a and MT4b. In *Arabidopsis* (Grennan, 2011), different MT isoforms MT1a, MT2a, MT2b, and MT3 are implicated in copper chelation, while MT4a and MT4b act as a zinc binder. In barely, MT3 maintains homeostasis of Zn and Cu, while MT4 was involved in Zn storage (Hegelund et al., 2012). MTs are synthesized through mRNA translation (Verkleij et al., 2003) and bind to different metals by establishing mercaptide bonds among the various Cys sublimates of the proteins and the metal (Blindauer and Leszczyszyn, 2010). Metal-MT complexes have low kinetic and high thermodynamic stability as a result, tight metal-binding occurs (Maret, 2000). MTs have been nominated as another method by which plants defend themselves from stress-generated oxidative injury (Hassinen et al., 2011; Ansarypour and Shahpiri, 2017). These have been reported to regulate cell growth, proliferation, immobilization, and DNA damage repair (Grennan, 2011), sequestration and detoxification of metal ions, or homeostasis of intracellular metal ions and their transport (Hossain et al., 2012; Guo et al., 2013), chelation of metal ions by MTs but their mechanism of action/transfer of metals-Metallothioneine system from the cytosol to the vacuole is not known (Yang et al., 2011; Liu et al., 2015). The

zinc contribution function of various metalloproteins is also observed (Cherian and Kang, 2006). A number of studies in plants reported the role of MTs in metal homeostasis. Metallothionein mRNA expression research revealed that higher Cr availability boosted MT gene expression. The upregulation of the MT gene due to high chromium levels in the growth medium may aid *Saccharum* spp. hybrid crop resistance to Cr toxicity (Jain et al., 2016). While there was no significant change in the expression level of two chelator genes, OsPCS1, and OsMT1, in roots and shoots of *Oryza sativa* L. (Pokkali and BRR1 51) during Cr stress (Kabir, 2016). Teixeira et al. (2013) showed that Cr (III) causes an elevation of MT2a-related transcripts in both roots and shoots and MT1- and MT2d-related transcripts only in roots, whereas Cr (VI) causes an elevation of MT2a- and MT2d-related transcripts only in roots. The de novo accumulation of the MT2c-related transcripts in shoots suggests that these MTs are related to the Cr homeostasis in *Solanum nigrum* (Teixeira et al., 2013). Benatti et al. (2014) reported that MTs impaired variants assemble lesser copper in roots and shoots. Transgenic plants overexpressing MTs genes reduce ROS production and increase metal tolerance (Tomas et al., 2015). Xia et al. (2012) observed that the exhibition of *E. hainchowsensis* MT1 (EhMT1) in *N. tabacum* L. plants not only enhanced the intensity of transgenic *N. tabacum* L. to Cu toxicity but also diminished the production of H₂O₂ and ameliorate peroxidase activity (POD) in roots, accelerated tolerance of plants to reduce oxidative damage.

Cr hyperaccumulator plants

Depending on the metal sensitivity and metal storing capability, plants can be categorized into excluders (metal sensitive plants), indicators (insufficient metal transfer and its consumption), and accumulators (higher consumption and storing) (Khan et al., 2009). Plant species that can store higher levels of HMs without yield reduction are known as metal hyperaccumulators (Memon and Schroder, 2009). They are used in phytoextraction because of their high accumulation capability (Cristaldi et al., 2017). The higher aggregation of metal in plants involves the transfer of metals beyond the cell-membrane, xylem loading, and transformation (rapid as well as active translocation of the metal to the shoot via the xylem, which is upregulated by transpiration) (Rees et al., 2016), detoxification and sequestration of metal (amino acids, organic acids or metal-binding peptides). The plants can be categorized as metal hyperaccumulators when they persist in nutrients and do not exhibit any injuries even after storing the toxic metals. A hyperaccumulator plant can extract the metal at concentrations ten times higher than their concentrations in the soil. Also, hyperaccumulator plants have a shoot-to-root metal ratio >1 (Tangahu et

al., 2011). About 721 hyperaccumulator plants (< 0.2% of entire flowering plants) are known. Hyperaccumulation depends on the metal, plant species, and soil physicochemical properties like hydrogen ion concentration, the extent of cation inter-change, litter, electroconductivity, etc. (Van der and Reeves, 2015). Cr hyperaccumulator plants may assemble greater than 1,000 mg Cr/kg dry weight of plant (leaves). These plants endure heavy metals stress through chelation (by appropriate connections with substances such as PCs, MTs, etc.), bioprocessing by reducing agents, and sequestration into the cytosol as well as in vacuoles. The metal uptake mainly depends on metal availability and the accumulator. The uptake, translocation, and accumulation of Cr in different plant parts tell the tolerance capability of the plant against Cr toxicity. Mainly species of the Brassicaceae family have been declared to assemble a significant amount of Cr. Some plants like *Genipa americana* (Barbosa et al., 2007), *Allium griffithianum*, *Catharanthus roseus* (Sajad et al., 2020), sunflower (Fozia et al., 2008; Farid et al., 2017), *V. radiata* (Jabeen et al., 2015), *Pluchea indica* (Sampapanish et al., 2006), *S. nigrum*, *B. napus* (Afshan et al., 2015; Li et al., 2018), sweet basil (Chand et al., 2015) and *Leersia hexandra* (You et al., 2014), etc., were found to be hyperaccumulators for Cr, while *Ipomoea aquatica* is a Cr (VI) tolerant plant with no toxicity signs up to 28 mg L⁻¹. *H. annuus* can assemble different heavy metals (HMs) like As (Imran et al., 2013), Cr (Fozia et al., 2008), Zn (Hao et al., 2012), Ni (Ahmad et al., 2011), Cd (Júnior et al., 2014), Cu (Lin et al., 2003) and Pb (Adesodun et al., 2010). *P. oleracea* is a Cr hyperaccumulator and tolerates high Cr (VI) concentration through different routes, either by the manufacturing of proline (retain osmotic stability) or by stimulating the antioxidant enzymes to prevent the oxidative stress of the heavy metals (Singh et al., 2013; Kale et al., 2015). Some hyperaccumulator plants are listed in Table 2. The assimilation of Cr by roots is promoted by organic compounds (available in the secretions of roots and make network with Cr) (Hayat et al., 2012) and stored in vacuoles of root cells (Babula et al., 2008). Bluskov et al. (2005) observed that in *B. juncea*, Cr formed a network with small molecular mass organic acids, which form Cr³⁺ (acetate) in roots and Cr³⁺ (oxalate) in leaves. The ability of *Ocimum basilicum* to condense harmful metals such as Cr, Cd, Cu, Pb, As, Zn, and Fe in their different parts, makes its use for the preparation of teas, spices, or raw materials consumption a potential health concern (Boechat et al., 2016).

Conclusion

Cr pollution increases continuously, which imposes a serious threat to the biosphere. Although plants have no special carrier for Cr uptake, they compete with oth-

er essential elements in the plant system and cause nutrient imbalance and leaf chlorosis. Cr can induce several toxic effects on plants, like low crop yield and nutrient starvation in vegetables and fruits. Higher Cr (III and IV) concentrations reduce plant growth, biomass, Chlorophyll biosynthesis, uptake of essential elements, antioxidant enzyme activities, and increase ROS in the plant system. The chlorosis, necrosis, and wilting are stimulated by Cr uptake in plants. Cr is seriously responsible for causing damage to DNA and lipid membranes. The Cr responsive proteins may get expressed from the functioning of MTs and HSPs genes. Various defence mechanisms implemented by plants like plant cell walls, plasma membrane, Cr sequestration, plant microbes, and chelation (PCs and MTs) are discussed herein.

Future prospectives

The newly expressed proteins study is important for abiotic stress research as Cr (VI) toxicity is fatal for plants. Therefore, it is necessary to recognize the possible mechanisms to diminish Cr uptake and lessen its harmful effects on the environment and ecosystem, mainly in plants. The mechanism inducing Cr toxicity at the proteomic and molecular levels still needs to be explored in detail.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Abbas, G., Murtaza, B., Bibi, I., Shahid, M., Niazi, N.K., Khan, M.I., Amjad, M. & Hussain, M. (2018). Arsenic Uptake, Toxicity, Detoxification, and Speciation in Plants: Physiological, Biochemical, and Molecular Aspects. *Int. J. Environ. Res. Pub. Health*, 15(1), 59. <https://doi.org/10.3390/ijerph15010059>
2. Adesodun, J.K., Atayese, M.O., Agbaje, T.A., Osadiaye, B.A., Mafe, O.F. & Soretire, A.A. (2010). Phytoremediation potentials of sunflowers (*Tithonia diversifolia* and *Helianthus annuus*) for metals in soils contaminated with zinc and lead nitrates. *Water Air Soil Pollut.*, 207, 195-201. <https://doi.org/10.1007/s11270-009-0128-3>
3. Adki, V.S., Jadhav, J.P. & Bapat, V.A. (2013). *Nopalea cochenillifera*, a potential chromium (VI) hyperaccumulator plant. *Environ. Sci. Pollut. Res.*, 20(2), 1173-1180. <https://doi.org/10.1007/s11356-012-1125-4>
4. Afonso, T.F., Demarco, C.F., Pieniz, S., Camargo, FAO., Quadro, M.S. & Andreatza, R. (2019). Potential of *Solanum viarum* Dunal in use for phytoremediation of heavy metals to mining areas, southern Brazil. *Env. Sci. Pollut. Res.*, 26, 24132–24142. <https://doi.org/10.1007/s11356-019-05460-z>
5. Afshan, S., Ali, S., Bharwana, S.A., Rizwan, M., Farid, M., Abbas, F., Ibrahim, M., Mehmood, M.A. & Abbasi, G.H. (2015). Citric acid enhances the phytoextraction of chromium, plant growth and photosynthesis by alleviating the oxidative damages in *Brassica napus* L. *Environ. Sci. Pollut. Res.*, 22, 11679–11689. <https://doi.org/10.1007/s11356-015-4396-8>
6. Agar, G., Taspinar, M.S., Yildirim, E., Aydin, M. & Yuce, M. (2020). Effects of ascorbic acid and copper treatments on metallothionein gene expression and antioxidant enzyme activities in *Helianthus annuus* L. exposed to chromium stress. *Plant Growth Regul.*, 39 (2), 897-904. <https://doi.org/10.1007/s00344-019-10031-0>
7. Ahemad, M. (2019). Remediation of metalliferous soils through the heavy metal resistant plant growth promoting bacteria: paradigms and prospects. *Arab. J. Chem.*, 12 (7), 1365-1377. <https://doi.org/10.1016/j.arabj.2014.1.020>
8. Ahmad, M.S.A., Ashraf, M. & Hussain, M. (2011). Phytotoxic effects of nickel on yield and concentration of macro- and micro-nutrients in sunflower (*Helianthus annuus* L.) achenes. *J. Hazard. Mater.*, 185, 1295-1303. <https://doi.org/10.1016/j.jhazmat.2010.10.045>
9. Ahmad, R., Ali, S., Abid, M., Rizwan, M., Ali, B., Tanveer, A. & Ghani, M.A. (2020). Glycine betaine alleviates the chromium toxicity in *Brassica oleracea* L. by suppressing oxidative stress and modulating the plant morphology and photosynthetic attributes. *Environ. Sci. Pollut. Res.*, 27(1), 1101-1111. <https://doi.org/10.1007/s11356-019-06761-z>
10. Alamri, S., Ali, H.M., Khan, M.I.R., Singh, V.P. & Siddiqui, M.H. (2020). Exogenous nitric oxide requires endogenous hydrogen sulphide to induce the resilience through sulphur assimilation in tomato seedlings under hexavalent chromium toxicity. *Plant Physiol. Biochem.*, 155, 20-34. <https://doi.org/10.1016/j.plaphy.2020.07.003>
11. Ali, H., Khan, E. & Sajad, M.A. (2013). Phytoremediation of heavy metals—concepts and applications. *Chemosphere* 91(7), 869–881. <https://doi.org/10.1016/j.chemosphere.2013.01.075>
12. Ali, S., Bharwana, S.A., Rizwan, M., Farid, M., Kanwal, S., Ali, Q., Ibrahim, M., Gill, R.A. & Khan, M.D. (2015). Fulvic acid mediates chromium (Cr) tolerance in wheat (*Triticum aestivum* L.) through lowering of Cr uptake and improved antioxidant defence system. *Environ. Sci. Pollut. Res.*, 22, 10601-10609. <https://doi.org/10.1007/s11356-015-4271-7>
13. Ali, S., Zeng, F., Cai, S., Qiu, B. & Zhang, G.P. (2011). The interaction of salinity and chromium in the influence of barley growth and oxidative stress. *Plant Soil Environ.*, 57(4), 153–159. <https://doi.org/10.17221/335/2010-PSE>
14. Anjana, K., Kaushik, A., Kiran, B. & Nisha, R. (2007). Biosorption of Cr (VI) by immobilized biomass of two indigenous strains of cyanobacteria isolated from metal contaminated soil. *J. Hazard. Mater.*, 148(1-2), 383-386. <https://doi.org/10.1016/j.jhazmat.2007.02.051>
15. Anjum, S.A., Ashraf, U., Imran, K.H.A.N., Tanveer, M., Shahid, M., Shakoor, A. & Longchang, W.A.N.G. (2017). Phyto-toxicity of chromium in maize: oxidative damage,

- osmolyte accumulation, anti-oxidative defence and chromium uptake. *Pedosphere* 27(2), 262-273. [https://doi.org/10.1016/S1002-0160\(17\)60315-1](https://doi.org/10.1016/S1002-0160(17)60315-1)
16. Ansarypour, Z. & Shahpiri, A. (2017) Heterologous expression of a rice metallothionein isoform (OsMTI-1b) in *Saccharomyces cerevisiae* enhances cadmium, hydrogen peroxide and ethanol tolerance. *Brazilian J. Microbiol.*, 48(3), 537–543. <https://doi.org/10.1016/j.bjm.2016.10.024>
 17. Arora, A., Saxena, S. & Sharma, D.K. (2006). Tolerance and phytoaccumulation of Chromium by three Azolla species. *World J. Microbiol. Biotechnol.*, 22(2), 97–100. <https://doi.org/10.1007/s11274-005-9000-9>
 18. Babula, P., Adam, V., Opatrilova, R., Zehnalek, J., Havel, L. & Kizek, R. (2008). Uncommon heavy metals, metalloids and their plant toxicity: A review. *Environ. Chem. Lett.*, 6(4), 189–213. https://doi.org/10.1007/978-1-4020-9654-9_14
 19. Barbosa, R.M.T., Almeida, A.A.F., Mielke, M.S., Loguercio, L.L., Mangabeira, P.A.O. & Gomes, F.P. (2007). A physiological analysis of *Genipa americana* L.: a potential phytoremediator tree for chromium polluted watersheds. *Environ. Exp. Bot.*, 61 (3), 264–271. <https://doi.org/10.1016/j.envexpbot.2007.06.001>
 20. Barton, L.L., Johnson, G.V., Onan, A.G. & Wagener, B.M. (2000). Inhibition of ferric chelate reductase in alfalfa roots by Cobalt, Nickel, Chromium, and Copper. *J. Plant Nutr. Soil Sci.*, 23(11-12), 1833–1845. <https://doi.org/10.1080/01904160009382146>
 21. Benatti, R.M., Yookongkaew, N., Meetam, M., Guo, W.J., Punyasuk, N., AbuQamar, S. & Goldsbrough, P. (2014). Metallothionein deficiency impacts copper accumulation and redistribution in leaves and seeds of Arabidopsis. *New Phytol.*, 202(3), 940-951. <https://doi.org/10.1111/nph.12718>
 22. Berni, R., Luyckx, M., Xu, X., Legay, S., Sergeant, K., Hausman, J.F., Lutts, S., Cai, G. & Guerriero, G. (2019). Reactive oxygen species and heavy metal stress in plants: impact on the cell wall and secondary metabolism. *Environ. Exp. Bot.*, 161, 98–106. <https://doi.org/10.1016/j.envexpbot.2018.10.017>
 23. Blindauer, C.A. & Leszczyszyn, O.I. (2010). Metallothioneins: unparalleled diversity in structures and functions for metal ion homeostasis and more. *Nat. Prod. Rep.*, 27, 720–741. <https://doi.org/10.1039/B906685N>
 24. Bloem, E., Haneklaus, S., Haensch, R. & Schnug, E. (2017). EDTA application on agricultural soils affects microelement uptake of plants. *Sci. Total Environ.*, 577, 166–173. <https://doi.org/10.1016/j.scitotenv.2016.10.153>
 25. Bluskov, S., Arocena, J.M., Omotoso, O.O. & Young, J.P. (2005). Uptake, distribution, and speciation of chromium in *Brassica juncea*. *Int. J. Phytorem.*, 7(2), 153-165. <https://doi.org/10.1080/16226510590950441>
 26. Boechat, C.L., Carlos, F.S., Gianello, C. & de Oliveira Camargo, F.A. (2016). Heavy metals and nutrients uptake by medicinal plants cultivated on multi-metal contaminated soil samples from an abandoned gold ore processing site. *Water Air Soil Pollut.*, 227(10), 1-11. <https://doi.org/10.1007/s11270-016-3096-4>
 27. Brasili, E., Bavasso, I., Petruccelli, V., Vilardi, G., Valletta, A., Dal Bosco, C. & Di Palma, L. (2020). Remediation of hexavalent chromium contaminated water through zero-valent iron nanoparticles and effects on tomato plant growth performance. *Sci. Rep.*, 10(1), 1-11. <https://doi.org/10.1038/s41598-020-58639-7>
 28. Braud, A., Jezequel, K., Bazot, S. & Lebeau, T. (2009). Enhanced phytoextraction of an agricultural Cr- and Pb-contaminated soil by bioaugmentation with siderophore-producing bacteria. *Chemosphere*, 74(2), 280-286. <https://doi.org/10.1016/j.chemosphere.2008.09.013>
 29. Brunetti, G., Farrag, K., Rovira, P.S., Nigro, F. & Senesi, N. (2011). Greenhouse and field studies on Cr, Cu, Pb and Zn phytoextraction by *Brassica napus* from contaminated soils in the Apulia region, Southern Italy. *Geoderma*, 160(3-4), 517–523. <https://doi.org/10.1016/j.geoderma.2010.10.023>
 30. Buendía-González, L., Orozco-Villafuerte, J., Cruz-Sosa, F., Barrera-Díaz, C.E. & Vernon-Carter, E.J. (2010). *Prosopis laevigata* a potential chromium (VI) and cadmium (II) hyperaccumulator desert plant. *Biores. Technol.*, 101(15), 5862-5867. <https://doi.org/10.1016/j.biortech.2010.03.027>
 31. Calheiros, C.S.C., Rangel, A.O.S.S. & Castro, P.M.L. (2008). The effects of tannery waste water on the development of different plant species and chromium accumulation in *Phragmites australis*. *Arch. Environ. Contam. Toxicol.*, 55(3), 404-414. <https://doi.org/10.1007/s00244-007-9087-0>
 32. Chand, S., Singh, S., Singh, V.K. & Patra, D.D. (2015). Utilization of heavy metal-rich tannery sludge for sweet basil (*Ocimum basilicum* L.) cultivation. *Environ. Sci. Pollut. Res.*, 22(10), 7470–7475. <https://doi.org/10.1007/s11356-015-4446-2>
 33. Chen, L., Luo, S., Li, X., Wan, Y., Chen, J. & Liu, C. (2014). Interaction of Cd-hyperaccumulator *Solanum nigrum* L. and functional endophyte *Pseudomonas* sp. Lk9 on soil heavy metals uptake. *Soil Biol. Biochem.*, 68, 300-308. <https://doi.org/10.1016/j.soilbio.2013.10.021>
 34. Chen, Q., Wu, K., Tang, Z., Guo, Q., Guo, X. & Wang, H. (2017). Exogenous ethylene enhanced the cadmium resistance and changed the alkaloid biosynthesis in *Catharanthus roseus* seedlings. *Acta Physiol. Plant.*, 39 (12), 1-12. <https://doi.org/10.1007/s11738-017-2567-6>
 35. Cherian, M.G. & Kang, Y.J. (2006). Metallothionein and liver cell regeneration. *Exp. Biol. Med.*, 231(2), 138–144. <https://doi.org/10.1177/153537020623100203>
 36. Choo, T.P., Lee, C.K., Low, K.S. & Hishamuddin, O. (2006). Accumulation of chromium (VI) from aqueous solutions using water lilies (*Nymphaea spontanea*). *Chemosphere*, 62(6), 961–967. <https://doi.org/10.1016/j.chemosphere.2005.05.052>
 37. Choppala, G., Kunhikrishnan, A., Seshadri, B., Park, J.H., Bush, R. & Bolan, N. (2018). Comparative sorption of chromium species as influenced by pH, surface charge and organic matter content in contaminated soils. *J. Geochem. Explor.*, 184, 255-260. <https://doi.org/10.1016/j.gexplo.2016.07.012>
 38. Clemens, S. (2006). Evolution and function of phytochelatin synthases. *J. Plant Physiol.*, 163(3), 319–332. <https://doi.org/10.1016/j.jplph.2005.11.010>
 39. Cristaldi, A., Conti, G.O., Jho, E.H., Zuccarello, P., Grasso, A., Copat, C. & Ferrante, M. (2017). Phytoremediation of contaminated soils by heavy metals and PAHs. A brief review. *Environ. Technol. Innov.*, 8, 309–326.

- <https://doi.org/10.1016/j.eti.2017.08.002>
40. Danish, S., Kiran, S., Fahad, S., Ahmad, N., Ali, M.A., Tahir, F.A., Rasheed, M.K., Shahzad, K., Li, X. & Wang, D. (2019). Alleviation of chromium toxicity in maize by Fe fortification and chromium tolerant ACC deaminase producing plant growth promoting rhizobacteria. *Ecotoxicol. Environ. Safety*, 185, 109706. <https://doi.org/10.1016/j.ecoenv.2019.109706>
 41. Del Bubba, M., Ancillotti, C., Checchini, L., Ciofi, L., Fibbi, D., Gonnelli, C. & Mosti, S. (2013). Chromium accumulation and changes in plant growth, selected phenolics and sugars of wild type and genetically modified *Nicotiana glauca*. *J. Hazard. Mater.*, 262, 394-403. <https://doi.org/10.1016/j.jhazmat.2013.08.073>
 42. Dey, S. & Paul, A.K. (2016). Evaluation of chromate reductase activity in the cell-free culture filtrate of *Arthrobacter* sp. SUK 1201 isolated from chromite mine overburden. *Chemosphere*, 156, 69-75. <https://doi.org/10.1016/j.chemosphere.2016.04.101>
 43. Dhir, B., Sharmila, P., Saradhi, P.P. & Nasim, S.A. (2009). Physiological and antioxidant responses of *Salvinia natans* exposed to chromium rich wastewater. *Ecotoxicol. Environ. Safety*, 72(6), 1790-1797. <https://doi.org/10.1016/j.ecoenv.2009.03.015>
 44. Diwan, H., Khan, I., Ahmad, A. & Iqbal, M. (2010) Induction of phytochelatin and antioxidant defence system in *Brassica juncea* and *Vigna radiata* in response to Cr treatments. *Plant Growth Regul.*, 61(1), 97-107. DOI 10.1007/s10725-010-9454-0
 45. Du, J., Yang, J.L. & Li, C.H. (2012) Advances in metallothionein studies in forest trees. *Plant OMICS*, 5(1), 46-51
 46. Eggs, N., Salvarezza, S., Azario, R., Fernández, N. & García, M.D.C. (2012). Adsorption de cromo hexavalente en la cáscara de arroz modificada químicamente. *Avances en ciencias e ingeniería*, 3(3), 141-151. <http://hdl.handle.net/20.500.12272/4908>
 47. Emamverdian, A., Ding, Y., Mokhberdoran, F. & Xie, Y. (2015). Heavy metal stress and some mechanisms of plant defence response. *Sci. World J.*, 756120. <https://doi.org/10.1155/2015/756120>
 48. Ertani, A., Mietto, A., Borin, M. & Nardi, S. (2017). Chromium in agricultural soils and crops: a review. *Water Air Soil Pollut.*, 228(5), 190. <https://doi.org/10.1007/s11270-017-3356-y>
 49. Fan, W.J., Feng, Y.X., Li, Y.H., Lin, Y.J. & Yu, X.Z. (2020). Unravelling genes promoting ROS metabolism in subcellular organelles of *Oryza sativa* in response to trivalent and hexavalent chromium. *Sci. Total Env.*, 744, 140951, 1-12. <https://doi.org/10.1016/j.scitotenv.2020.140951>
 50. Farid, M., Ali, S., Akram, N.A., Rizwan, M., Abbas, F., Bukhari, S.A.H. & Saeed, R. (2017). Phyto-management of Cr contaminated soils by sunflower hybrids: physiological and biochemical response and metal extractability under Cr stress. *Environ. Sci. Pollut. Res.*, 24(20), 16845-16859. <https://doi.org/10.1007/s11356-017-9247-3>
 51. Farid, M., Ali, S., Rizwan, M., Yasmeen, T., Arif, M.S., Riaz, M. & Ayub, M.A. (2020). Combined effects of citric acid and 5-aminolevulinic acid in mitigating chromium toxicity in sunflower (*Helianthus annuus* L.) grown in Cr spiked soil. *Pak. J. Agric. Sci.*, 57(2), 477-488. DOI: 10.21162/PAKJAS/20.9332
 52. Feng, Y.X., Yu, X.Z., Mo, C.H. & Lu, C.J. (2019). Regulation network of sucrose metabolism in response to trivalent and hexavalent chromium in *Oryza sativa*. *J. Agric. Food Chem.*, 67, 9738-9748. <https://doi.org/10.1021/acs.jafc.9b01720>
 53. Fidalgo, F., Azenha, M., Silva, A.F., de Sousa, A., Santiago, A., Ferraz, P. & Teixeira, J. (2013). Copper-induced stress in *Solanum nigrum* L. and antioxidant defence system responses. *Food Energy Sec.*, 2(1), 70-80. <https://doi.org/10.1002/fes3.20>
 54. Flores-Alvarez, L.J., Corrales-Escobosa, A.R., Cortés-Penagos, C., Martínez-Pacheco, M., Wrobel-Zasada, K., Wrobel-Kaczmarczyk, K. & Gutiérrez-Corona, F. (2012). The *Neurospora crassa* chr-1 gene is upregulated by chromate and its encoded CHR-1 protein causes chromate sensitivity and chromium accumulation. *Curr. Genet.*, 58(5), 281-290. <https://doi.org/10.1007/s00294-012-0383-5>
 55. Fozia, A., Muhammad, A.Z., Muhammad, A. & Zafar, M.K. (2008). Effect of chromium on growth attributes in sunflower (*Helianthus annuus* L.). *J. Env. Sci.*, 20(12), 1475-1480. [https://doi.org/10.1016/S1001-0742\(08\)62552-8](https://doi.org/10.1016/S1001-0742(08)62552-8)
 56. Gardea-Torresdey, J.L., Peralta-Videa, J.R., Montes, M., De la Rosa, G. & Corral-Diaz, B. (2004). Bioaccumulation of cadmium, chromium and copper by *Convolvulus arvensis* L.: impact on plant growth and uptake of nutritional elements. *Biores. Technol.*, 92(3), 229-235. <https://doi.org/10.1016/j.biortech.2003.10.002>
 57. Gautam, V., Sharma, P., Bakshi, P., Arora, S., Bhardwaj, R., Paray, B.A. & Ahmad, P. (2020). Effect of *Rhododendron arboreum* Leaf Extract on the Antioxidant Defence System against Chromium (VI) Stress in *Vigna radiata* Plants. *Plants*, 9(2), 1-22. <https://doi.org/10.3390/plants9020164>
 58. Gill, R.A., Ali, B., Islam, F., Farooq, M.A., Gill, M.B., Mwamba, T.M. & Zhou, W. (2015). Physiological and molecular analyses of black and yellow seeded *Brassica napus* regulated by 5-aminolevulinic acid under chromium stress. *Plant Physiol. Biochem.*, 94, 130-143. <https://doi.org/10.1016/j.plaphy.2015.06.001>
 59. Gill, R. A., Zhang, N., Ali, B., Farooq, M. A., Xu, J., Gill, M. B. & Zhou, W. (2016). Role of exogenous salicylic acid in regulating physio-morphic and molecular changes under Cr toxicity in black-and yellow-seeded *Brassica napus* L. *Environmental Science and Pollution Research*, 23(20), 20483-20496. <https://doi.org/10.1007/s11356-016-7167-2>
 60. Gill, R. A., Hu, X. Q., Ali, B., Yang, C., Shou, J. Y., Wu, Y. Y. & Zhou, W. J. (2014). Genotypic variation of the responses to chromium toxicity in four oilseed rape cultivars. *Biologia plantarum*, 58(3), 539-550. <https://doi.org/10.1007/s10535-014-0430-9>
 61. Gill, R. A., Ali, B., Yang, S., Tong, C., Islam, F., Gill, M. B. & Zhou, W. (2017). Reduced glutathione mediates pheno-ultrastructure, kinome and transportome in chromium-induced *Brassica napus* L. *Frontiers in plant science*, 8, 2037. <https://doi.org/10.3389/fpls.2017.02037>
 62. Gharieb, M.M. & Gadd, G.M. (2004). Role of glutathione in detoxification of metal (loid) s by *Saccharomyces*

- cerevisiae*. *Biometals*, 17(2), 183-188.
63. Gomes, M.A. da C, Hauser-Davis, R.A., Suzuki, M.S. & Vitoria, A.P. (2017). Plant chromium uptake and transport, physiological effects and recent advances in molecular investigations. *Ecotoxicol. Environ. Safety*, 140, 55-64. <https://doi.org/10.1016/j.ecoenv.2017.01.042>
 64. Grennan, A.K. (2011). Metallothioneins, a diverse protein family. *Plant Physiol.*, 155(4), 1750–1751. <https://doi.org/10.1104/pp.111.900407>
 65. Guo, J., Xu, L., Su, Y., Wang, H., Gao, S., Xu, J. & Que, Y. (2013). ScMT2-1-3, a metallothionein gene of sugarcane, plays an important role in the regulation of heavy metal tolerance/accumulation. *BioMed Res. Int.*, 2013, 1-12. <https://doi.org/10.3389/fpls.2017.02262>
 66. Gupta, D., Vandenhove, H. & Inouhe, M. (2013). Role of phytochelatin in heavy metal stress and detoxification mechanisms in plants. In: *Heavy Metal Stress in Plants*, 73–94. https://doi.org/10.1007/978-3-642-38469-1_4
 67. Gupta, P., Rani, R., Chandra, A., Varjani, S.J. & Kumar, V. (2017). Effectiveness of plant growth-promoting rhizobacteria in phytoremediation of chromium stressed soils. *Bioresour. J.*, 301–312. https://doi.org/10.1007/978-981-10-7413-4_16
 68. Hall, J.L. (2002). Cellular mechanisms for heavy metal detoxification and tolerance. *J. Exp. Bot.*, 53(366), 1–11. <https://doi.org/10.1093/jexbot/53.366.1>
 69. Hao, X.Z., Zhou, D.M., Li, D.D. & Jiang, P. (2012). Growth, cadmium and zinc accumulation of ornamental sunflower (*Helianthus annuus* L.) in contaminated soil with different amendments. *Pedosphere*, 22(5), 631-639. [https://doi.org/10.1016/S1002-0160\(12\)60048-4](https://doi.org/10.1016/S1002-0160(12)60048-4)
 70. Haque, N., Peralta-Videa, J.R., Jones, G.L., Gill, T.E. & Gardea-Torresdey, J.L. (2008). Screening the phytoremediation potential of desert broom (*Baccharis sarothroides* Gray) growing on mine tailings in Arizona, USA. *Environ. Pollut.*, 153(2), 362–368 <https://doi.org/10.1016/j.envpol.2007.08.024>.
 71. Harmens, H., DenHartog, P.R., ten Bookum, W.M. & Verkleij, J.A.C. (1993). Increased zinc tolerance in *Silene vulgaris* (Moench) Garcke is not due to increased production of phytochelatin. *Plant Physiol.*, 103, 1305–1309. <https://doi.org/10.1104/pp.103.4.1305>
 72. Hassinen, V.H., Tervahauta, A.I., Schat, H. & Kärenlampi, S.O. (2011). Plant metallothioneins–metal chelators with ROS scavenging activity. *Plant Biol.*, 13(2), 225–232. <https://doi.org/10.1111/j.1438-8677.2010.00398.x>
 73. Hayat, S., Khalique, G., Irfan, M., Wani, A.S., Tripathi, B.N. & Ahmad, A. (2012). Physiological changes induced by chromium stress in plants: An overview. *Protoplasma*, 249(3), 599–611. <https://doi.org/10.1007/s00709-011-0331-0>
 74. Hegelund, J.N., Schiller, M., Kichey, T., Hansen, T.H., Pedas, P., Husted, S. & Schjoerring, J.K. (2012). Barley metallothioneins: MT3 and MT4 are localized in the grain aleurone layer and show differential zinc binding. *Plant Physiol.*, 159(3), 1125-1137. <https://doi.org/10.1104/pp.112.197798>
 75. Heiss, S., Wachter, A., Bogs, J., Cobbett, C. & Rausch, T. (2003). Phytochelatin synthase (PCS) protein is induced in *Brassica juncea* leaves after prolonged Cd exposure. *J. Exp. Bot.*, 54(389), 1833–1839. <https://doi.org/10.1093/jxb/erg205>
 76. Hose, G.C., Symington, K., Lott, M.J. & Lategan, M.J. (2016). The toxicity of arsenic (III), chromium (VI) and zinc to groundwater copepods. *Environ. Sci. Pollut. Res.*, 23(18), 18704-18713. <https://doi.org/10.1007/s11356-016-7046-x>
 77. Hossain, M.A., Piyatida, P., da Silva, J.A.T. & Fujita, M. (2012). Molecular mechanism of heavy metal toxicity and tolerance in plants: central role of glutathione in detoxification of reactive oxygen species and methylglyoxal and in heavy metal chelation. *J. Bot.*, 872-875. doi:10.1155/2012/872875
 78. Hourri, T., Khairallah, Y., Al Zahab, A., Osta, B., Romanos, D. & Haddad, G. (2020). Heavy metals accumulation effects on the photosynthetic performance of geophytes in Mediterranean reserve. *J. King Saud Univ. – Sci.*, 32(1), 874-880. <https://doi.org/10.1016/j.jksus.2019.04.005>
 79. Huang, G.Y. & Wang, Y.S. (2009). Expression analysis of type 2 metallothionein gene in mangrove species (*Bruguiera gymnorrhiza*) under heavy metal stress. *Chemosphere*, 77(7), 1026–1029. <https://doi.org/10.1016/j.chemosphere.2009.07.073>
 80. Huda, A.K.M., Swaraz, A.M., Reza, M.A., Haque, M.A. & Kabir, A.H. (2016). Remediation of chromium toxicity through exogenous salicylic acid in rice (*Oryza sativa* L.). *WaterAir Soil Pollut.*, 227(8), 1-11. DOI 10.1007/s11270-016-2985-x
 81. Huda, A.N., Haque, M.A., Zaman, R., Swaraz, A.M. & Kabir, A.H. (2017). Silicon ameliorates chromium toxicity through phytochelatin-mediated vacuolar sequestration in the roots of *Oryza sativa* (L.). *Int. J. Phytorem.*, 19(3), 246-253. <https://doi.org/10.1080/15226514.2016.1211986>
 82. Hussain, A., Ali, S., Rizwan, M., Rehman, M.Z., Hameed, A., Hafeez, F., Alamri, S.A., Alyemeni, M.N. & Wijaya, L. (2018). Role of zinc–lysine on growth and chromium uptake in rice plants under Cr stress. *J. Plant Growth Regul.*, 37(4), 1413-1422. <https://doi.org/10.1007/s00344-018-9831-x>
 83. Imran, M.A., Khan, R.M., Ali, Z. & Mahmood, T. (2013). Toxicity of arsenic (As) on seed germination of sunflower (*Helianthus annuus* L.). *Int. J. Phys. Sci.*, 8(17), 840-847. <https://doi.org/10.5897/IJPS2013.3894>
 84. Islam, F., Yasmeen, T., Arif, M.S., Riaz, M., Shahzad, S.M., Imran, Q. & Ali, I. (2016). Combined ability of chromium (Cr) tolerant plant growth promoting bacteria (PGPB) and salicylic acid (SA) in attenuation of chromium stress in maize plants. *Plant Physiol. Biochem.*, 108, 456-467. <https://doi.org/10.1016/j.plaphy.2016.08.014>
 85. Jabeen, N., Abbas, Z., Iqbal, M., Rizwan, M., Jabbar, A., Farid, M., Ali, S., Ibrahim, M. & Abbas, F. (2015). Glycine betaine mediates chromium tolerance in mung bean through lowering of Cr uptake and improved antioxidant system. *Arch. Agron. Soil Sci.*, 62(5), 648–662. <https://doi.org/10.1080/03650340.2015.1082032>
 86. Jain, R., Singh, S.P., Singh, A., Singh, S., Tripathi, P., Chandra, A. & Solomon, S. (2016). Study on physio-biochemical attributes and metallothionein gene expression affected by chromium (VI) in sugarcane (*Saccharum* spp. hybrid). *J. Env. Biol.*, 37(3), 375.
 87. Joutey, N.T., Sayel, H., Bahafid, W. & El Ghachtouli, N.

- (2015). Mechanisms Cr (VI) resistance and removal by microorganisms. *Rev. Env. Contam. Toxicol.*, 233, 45-69. https://doi.org/10.1007/978-3-319-10479-9_2
88. Junior, C.A.L., Mazzafera, P. & Arruda, M.A.Z. (2014). A comparative ionic approach focusing on cadmium effects in sunflowers (*Helianthus annuus* L.). *Environ. Exp. Bot.*, 107, 180-186. <https://doi.org/10.1016/j.envexpbot.2014.06.002>
89. Kabir, A.H. (2016). Biochemical and molecular changes in rice seedlings (*Oryza sativa* L.) to cope with Cr stress. *Plant Biol.*, 18(4), 710-719. <https://doi.org/10.1111/plb.12436>
90. Kale, R.A., Lokhande, V.H. & Ade, A.B. (2015). Investigation of chromium phytoremediation and tolerance capacity of a weed, *Portulaca oleracea* L. in a hydroponic system. *Water Environ. J.*, 29(2), 236– 242. <https://doi.org/10.1111/wej.12106>
91. Karthik, C. & Arulselvi, P.I. (2017). Bio-toxic effect of chromium (VI) on plant growth promoting traits of novel *Cellulosi* microbium funkei strain AR8 isolated from *Phaseolus vulgaris* rhizosphere. *Geomicrobiol. J.*, 34(5), 434-442. <https://doi.org/10.1080/01490451.2016.1219429>
92. Karthik, C., Elangovana, N., Senthil Kumara, T., Govindharajua, S., Barathia, S., Ovesc, M. & Arulselvi, P.I. (2017). Characterization of multifarious plant growth promoting traits of rhizobacterial strain AR6 under Chromium (VI) stress. *Microbiol. Res.*, 204, 65–71. <https://doi.org/10.1016/j.micres.2017.07.008>
93. Karthik, C., Oves, M., Thangabalu, R., Sharma, R., Santhosh, S.B. & Arulselvi, P.I. (2016). Cellulosimicrobium funkei-like enhances the growth of *Phaseolus vulgaris* by modulating oxidative damage under chromium (VI) toxicity. *J. Adv. Res.*, 7(6), 839–850. <https://doi.org/10.1016/j.jare.2016.08.007>
94. Kaur, R., Yadav, P., Thukral, A.K., Sharma, A., Bhardwaj, R., Alyemeni, M.N., Wijaya, L. & Ahmad, P. (2018). Castasterone and citric acid supplementation alleviates cadmium toxicity by modifying antioxidants and organic acids in *Brassica juncea*. *J. Plant Growth Regul.*, 37(1), 286-299. <https://doi.org/10.1007/s00344-017-9727-1>
95. Khan, M.S., Zaidi, A., Ahmad, W.P. & Oves, M. (2009). Role of plant growth promoting rhizobacteria in the remediation of metal contaminated soils: a review. *Sustain. Agric. Res.*, 1, 319-350. <https://doi.org/10.1007/s10311-008-0155-0>
96. Khanna, K., Jamwal, V.L., Sharma, A., Gandhi, S.G., Ohri, P., Bhardwaj, R., Al-Huqail, A.A., Siddiqui, M.H., Ali, H.M. & Ahmad, P. (2019). Supplementation with plant growth promoting rhizobacteria (PGPR) alleviates cadmium toxicity in *Solanum lycopersicum* by modulating the expression of secondary metabolites. *Chemosphere*, 230, 628–639. <https://doi.org/10.1016/j.chemosphere.2019.05.072>
97. Kneer, R. & Zenk, M.H. (1992). Phytochelatins protect plant enzymes from heavy metal poisoning. *Phytochem.*, 31(8), 2663-2667. [https://doi.org/10.1016/0031-9422\(92\)83607-Z](https://doi.org/10.1016/0031-9422(92)83607-Z)
98. Kohler, A., Blaudez, D., Chalot, M. & Martin, F. (2004). Cloning and expression of multiple metallothioneins from hybrid poplar. *New Phytol.*, 164(1), 83–93. doi: 10.1111/j.1469-8137
99. Krzeslowska, M. (2011). The wall cell in plant cell response to trace metals: Polysaccharide remodelling and its role in defence strategy. *Acta Physiol. Plant.*, 33(1), 35–51. <https://doi.org/10.1007/s11738-010-0581-z>
100. Kumar, R., Mishra, R. K., Mishra, V., Qidwai, A., Pandey, A., Shukla, S. K. & Dikshit, A. (2016). Detoxification and tolerance of heavy metals in plants. In *Plant metal interaction*, 335-359. Elsevier. <https://doi.org/10.1016/B978-0-12-803158-2.00013-8>
101. Kushwaha, B.K., Singh, S., Tripathi, D.K., Sharma, S., Prasad, S.M., Chauhan, D.K., Kumar, V. & Singh, V.P. (2019). New adventitious root formation and primary root biomass accumulation are regulated by nitric oxide and reactive oxygen species in rice seedlings under arsenate stress. *J. Hazar. Mater.*, 361, 134-140. <https://doi.org/10.1016/j.jhazmat.2018.08.035>
102. Kushwaha, B.K. & Singh, V.P. (2020). Glutathione and hydrogen sulfide are required for sulfur-mediated mitigation of Cr (VI) toxicity in tomato, pea and brinjal seedlings. *Plant Physiol.*, 168(2), 406-421. <https://doi.org/10.1111/ppl.13024>
103. Lena, Q.M. & Rao, G.N. (1997). Chemical Fractionation of Cadmium, Copper, Nickel, and Zinc in Contaminated Soils. *J. Env. Qual.*, 26, 259-264. <https://doi.org/10.2134/jeq1997.00472425002600010036x>
104. Levizou, E., Zanni, A.A. & Antoniadis, V. (2018). Varying concentrations of soil chromium (VI) for the exploration of tolerance thresholds and phytoremediation potential of the oregano (*Origanum vulgare*). *Environ. Sci. Pollut. Res.*, 26, 14–23. <https://doi.org/10.1007/s11356-018-2658-y>
105. Li, J.T., Gurajala, H.K., Wu, L.H., van der Ent, A., Qiu, R.L., Baker, A.J.M., Tang, Y.T., Yang, X.E. & Shu, W.S. (2018). Hyperaccumulator plants from China: A synthesis of the current state of knowledge. *Environ. Sci. Technol.*, 52(21), 11980-11994. <https://doi.org/10.1021/acs.est.8b01060>
106. Lin, J., Jiang, W. & Liu, D. (2003). Accumulation of copper by roots, hypocotyls, cotyledons and leaves of sunflower (*Helianthus annuus* L.). *Biores. Technol.*, 86(2), 151-155. [https://doi.org/10.1016/S0960-8524\(02\)00152-9](https://doi.org/10.1016/S0960-8524(02)00152-9)
107. Liu, J., Duan, C., Zhang, X., Zhu, Y. & Lu, X. (2011). Potential of *Leersia hexandra* Swartz for phytoextraction of Cr from soil. *J. Hazar. Mater.*, 188(1-3), 85-91. <https://doi.org/10.1016/j.jhazmat.2011.01.066>
108. Liu, J., Shi, X., Qian, M., Zheng, L., Lian, C., Xia, Y. & Shen, Z. (2015). Copper-induced hydrogen peroxide upregulation of a metallothionein gene, OsMT2c, from *Oryza sativa* L. confers copper tolerance in *Arabidopsis thaliana*. *J. Hazar. Mater.*, 294, 99-108. <https://doi.org/10.1016/j.jhazmat.2015.03.060>
109. Lopez-Luna, J., Gonzalez-Chavez, M., Esparza-Garcia, F. & Rodriguez-Vazquez, R. (2009). Toxicity assessment of soil amended with tannery sludge, trivalent chromium and hexavalent chromium, using wheat, oat and sorghum plants. *J. Hazar. Mater.*, 163 (2), 829-834. <https://doi.org/10.1016/j.jhazmat.2008.07.034>
110. Ma, Y., Prasad, M.N., Rajkumar, M. & Freitas, H. (2011). Plant growth promoting rhizobacteria and endophytes accelerate phytoremediation of metalliferous soils. *Bio-technol. Adv.*, 29(2), 248-258. <https://doi.org/10.1016/j.biotechadv.2010.12.001>

111. Malandrino, M., Giacomino, A., Karthik, M., Zelano, I., Fabbri, D., Ginepro, M. & Abollino, O. (2017). Inorganic markers profiling in wild type and genetically modified plants subjected to abiotic stresses. *Microchem. J.*, 134, 87-97. <https://doi.org/10.1016/j.microc.2017.04.023>
112. Maleki, M., Ghorbanpour, M. & Kariman, K. (2017). Physiological and antioxidative responses of medicinal plants exposed to heavy metals stress. *Plant Gene*, 11, 247–254. <https://doi.org/10.1016/j.plgene.2017.04.006>
113. Mallhi, A.I., Chatha, S.A.S., Hussain, A.I., Rizwan, M., Bukhar, S.A.H., Hussain, A. & Alyemeni, M.N. (2020). Citric acid assisted phytoremediation of chromium through sunflower plants irrigated with tannery wastewater. *Plants*, 9(3), 380. <https://doi.org/10.3390/plants9030380>
114. Mallhi, Z.I., Rizwan, M., Mansh, A., Ali, Q., Asim, S., Ali, S., Hussain, A., Alrokayan, S.H., Khan, H.A. & Alam, P. (2019). Citric Acid Enhances Plant Growth, Photosynthesis, and Phytoextraction of Lead by Alleviating the Oxidative Stress in Castor Beans. *Plants*, 8(11), 525. <https://doi.org/10.3390/plants8110525>
115. Margoshes, M. & Vallee, B.L. (1957). A cadmium protein from equine kidney cortex. *J. Amer. Chem. Soc.*, 79(17), 4813-4814. <https://doi.org/10.1021/ja01574a064>
116. Mehdipour, S., Vatanpour, V. & Kariminia, H.R. (2015). Influence of ion interaction on lead removal by a polyamide nanofiltration membrane. *Desalination*, 362, 84-92. <https://doi.org/10.1016/j.desal.2015.01.030>
117. Memon, A.R., Aktoprakligil, D., Zdemur, A. & Vertii, A. (2001). Heavy metal accumulation and detoxification mechanisms in plants. *Turk. J. Bot.*, 25(3), 111-121.
118. Memon, A.R. & Schroder, P. (2009). Implications of metal accumulation mechanisms to phytoremediation. *Environ. Sci. Pollut. Res.*, 16(2), 162-175. <https://doi.org/10.1007/s11356-008-0079-z>
119. Mittler, R. (2017). ROS is good. *Trends Plant Sci.*, 22(1), 11-19. <https://doi.org/10.1016/j.tplants.2016.08.002>
120. Mittler, R., Vanderauwera, S., Suzuki, N., Miller, G., Tognetti, V.B., Vandepoele, K., Gollery, M., Shulaev, V. & Van Breusegem, F. (2011). ROS signaling: the new wave? *Trends Plant Sci.*, 16(6), 300–309. <https://doi.org/10.1016/j.tplants.2011.03.007>
121. Mohanty, M. & Patra, H.K. (2020). Phyto-assessment of in situ weed diversity for their chromium distribution pattern and accumulation indices of abundant weeds at South Kaliapani chromite mining area with their phytoremediation prospective. *Ecotoxicol. Environ. Saf.*, 194, 110399. <https://doi.org/10.1016/j.ecoenv.2020.110399>
122. Mongkhonsin, B., Nakbanpote, W., Nakai, I., Hokura, A. & Jearanaikoon, N. (2011). Distribution and speciation of chromium accumulated in *Gynura pseudochina* (L.) DC. *Environ. Exp. Bot.*, 74, 56-64. <https://doi.org/10.1016/j.envexpbot.2011.04.018>
123. Mukta, R.H., Khatun, M.R. & Nazmul Huda, A.K.M. (2019). Calcium induces phytochelatin accumulation to cope with chromium toxicity in rice (*Oryza sativa* L.). *J. Plant Interac.*, 14(1), 295-302. <https://doi.org/10.1080/17429145.2019.1629034>
124. Naseem, S., Yasin, M., Ahmed, A. & Faisal, M. (2015). Chromium Accumulation and Toxicity in Corn (*Zea mays* L.) Seedlings. *Polish J. Environ. Stud.*, 24(2), 899-904.
125. Nieboer, E. & Richardson, D.H.S. (1980). The replacement of the nondescript term %heavy metals by a biologically and chemically significant classification of metal ions. *Environ. Pollut. Series B: Chem. Phys.*, 1(1), 3–26. [https://doi.org/10.1016/0143-148X\(80\)90017-8](https://doi.org/10.1016/0143-148X(80)90017-8)
126. Oh, Y.J., Song, H., Shin, W.S., Choi, S.J. & Kim, Y.H. (2007). Effect of amorphous silica and silica sand on removal of chromium (VI) by zero-valent iron. *Chemosphere*, 66(5), 858-865. <https://doi.org/10.1016/j.chemosphere.2006.06.034>
127. Pandey, V., Dixit, V. & Shyam, R. (2005). Antioxidative responses in relation to growth of mustard (*Brassica juncea* cv. Pusa Jaikisan) plants exposed to hexavalent chromium. *Chemosphere*, 61(1), 40-47. <https://doi.org/10.1016/j.chemosphere.2005.03.026>
128. Patra, D.K., Pradhan, C. & Patra, H.K. (2019). Chromium bioaccumulation, oxidative stress metabolism and oil content in lemon grass *Cymbopogon flexuosus* (Nees ex Steud.) W. Watson grown in chromium rich over burden soil of Sukinda chromite mine, India. *Chemosphere*, 218, 1082-1088. <https://doi.org/10.1016/j.chemosphere.2018.11.211>
129. Pelloux, J., Rusterucci, C. & Mellerowicz, E.J. (2007). New insight into pectin methyl esterase structure and function. *Trends Plant Sci.*, 12(6), 267-277. <https://doi.org/10.1016/j.tplants.2007.04.001>
130. Piechalak, A., Tomaszewska, B., Baralkiewicz, D. & Malicka, A. (2002) Accumulation and detoxification of lead ions in legumes. *Phytochem.*, 60(2), 153–162. [https://doi.org/10.1016/S0031-9422\(02\)00067-5](https://doi.org/10.1016/S0031-9422(02)00067-5)
131. Postrigan, B.N., Knyaze, A.B., Kuluev, B.R., Yakhin, O.I. & Chemeris, A.V. (2012). Expression of the synthetic phytochelatin gene in tobacco. *Russian J. Plant Physiol.*, 59(2), 275–280. <https://doi.org/10.1134/S1021443712020136>
132. Qi, Q., Guo, Z., Liang, Y., Li, K. & Xu, H. (2019). Hydrogen sulphide alleviates oxidative damage under excess nitrate stress through MAPK/NO signalling in cucumber. *Plant Physiol. Biochem.*, 135, 1-8. <https://doi.org/10.1016/j.plaphy.2018.11.017>
133. Qureshi, F.F., Ashraf, M.A., Rasheed, R., Ali, S., Hussain, I., Ahmed, A. & Iqbal, M. (2020). Organic chelates decrease phytotoxic effects and enhance chromium uptake by regulating chromium-speciation in castor bean (*Ricinus communis* L.). *Sci. Total Environ.*, 716, 137061, 1-13. <https://doi.org/10.1016/j.scitotenv.2020.137061>
134. Rabelo, F.H.S., Fernie, A.R., Navazas, A., Borgo, L., Keunen, E., da Silva, B.K.D.A., Cuypers, A. & Lavres, J. (2018). A glimpse into the effect of sulfur supply on metabolite profiling, glutathione and phytochelatin in *Panicum maximum* cv. Massai exposed to cadmium. *Environ. Exp. Bot.*, 151, 76-88. <https://doi.org/10.1016/j.envexpbot.2018.04.003>
135. Rai, V., Vajpayee, P., Singh, S.N. & Mehrotra, S. (2004). Effect of chromium accumulation on photosynthetic pigments, oxidative stress defence system, nitrate reduction, proline level and eugenol content of *Ocimum tenuiflorum* L. *Plant Sci.*, 167(5), 1159-1169. <https://doi.org/10.1016/j.plantsci.2004.06.016>
136. Rajkumar, M., Ae, N., Prasad, M.N. & Freitas, H. (2010). Potential of siderophore-producing bacteria for improving heavy metal phytoextraction. *Trends Biotechnol.*, 28(3), 142-149. <https://doi.org/10.1016/j.tibtech.2009.12.002>

137. Ram, N.B., Gaurav, S. & Sikandar, I.M. (2019). Introduction to Industrial Wastes Containing Organic and Inorganic Pollutants and Bioremediation Approaches for Environmental Management- Book Chapter. *Bioremediation of Industrial Waste for Environmental Safety*. Springer Publications. 1-18. https://doi.org/10.1007/978-981-13-1891-7_1
138. Ranieri, E., Fratino, U., Petruzzelli, D. & Borges, A.C. (2013). A comparison between *Phragmites australis* and *Helianthus annuus* in chromium phytoextraction. *Water Air Soil Pollut.*, 224, 1–9. <https://doi.org/10.1007/s11270-013-1465-9>
139. Rauser, W.E., Schupp, R. & Rennenberg, H. (1991). Cysteine, γ -glutamylcysteine, and glutathione levels in maize seedlings. *Plant Physiol.*, 97(1), 128-138. <https://doi.org/10.1104/pp.97.1.128>
140. Redondo-Gómez, S., Mateos-Naranjo, E., Vecino-Bueno, I. & Feldman, S.R. (2011). Accumulation and tolerance characteristics of chromium in a cordgrass Cr-hyperaccumulator, *Spartina argentinensis*. *J. Hazard. Mater.*, 185(2-3), 862-869. <https://doi.org/10.1016/j.jhazmat.2010.09.101>
141. Rees, F., Sterckeman, T. & Morel, J.L. (2016). Root development of non-accumulating and hyperaccumulating plants in metal-contaminated soils amended with biochar. *Chemosphere*, 142, 48-55. <https://doi.org/10.1016/j.chemosphere.2015.03.068>
142. Sacky, J., Leonhardt, T., Borovicka, J., Gryndler, M., Briksi, A. & Kotrba, P. (2014). Intracellular sequestration of zinc, cadmium and silver in *Hebeloma mesophaeum* and characterization of its metallothionein genes. *Fungal Genet. Biol.*, 67, 3-14. <https://doi.org/10.1016/j.fgb.2014.03.003>
143. Sajad, M.A., Khan, M.S., Bahadur, S., Naeem, A., Ali, H., Batool, F. & Batool, S. (2020). Evaluation of chromium phytoremediation potential of some plant species of Dir Lower, Khyber Pakhtunkhwa, Pakistan. *Acta Ecologica Sinica*, 40(2), 158-165. <https://doi.org/10.1016/j.chnaes.2019.12.002>
144. Saleem, M.H., Ali, S., Hussain, S., Kamran, M., Chattha, M.S., Ahmad, S., Aqeel, M., Rizwan, M., Aljarba, N.H. & Alkahtani, S. (2020a). Flax (*Linum usitatissimum* L.): A Potential Candidate for Phytoremediation? Biological and Economical Points of View. *Plants*, 9(4), 496. <https://doi.org/10.3390/plants9040496>
145. Saleem, M.H., Fahad, S., Adnan, M., Ali, M., Rana, M.S., Kamran, M. & Hussain, R.M. (2020c). Foliar application of gibberellic acid endorsed phytoextraction of copper and alleviates oxidative stress in jute (*Corchorus capsularis* L.) plant grown in highly copper-contaminated soil of China. *Environ. Sci. Pollut. Res.*, 27(29), 37121-37133. <https://doi.org/10.1007/s11356-020-09764-3>
146. Saleem, M.H., Fahad, S., Rehman, M., Saud, S., Jamal, Y., Khan, S. & Liu, L. (2020d). Morpho-physiological traits, biochemical response and phytoextraction potential of short-term copper stress on kenaf (*Hibiscus cannabinus* L.) seedlings. *J. Life Environ. Sci.*, 8, e8321. <https://doi.org/10.7717/peerj.8321>
147. Sampanpanish, P., Pongsapich, W., Khaodhiar, S. & Khan, E. (2006). Chromium removal from soil by phytoremediation with weed plant species in Thailand. *Water Air Soil Pollut.*, 6(1-2), 191-206. <https://doi.org/10.1007/s11267-005-9006-1>
148. Sanjay, M.S., Sudarsanam, D., Raj, G.A. & Baskar, K. (2020). Isolation and identification of chromium reducing bacteria from tannery effluent. *J. King Saud Univ. – Sci.*, 32(1), 265-271. <https://doi.org/10.1016/j.jksus.2018.05.001>
149. Scheller, H.V. & Ulvskov, P. (2010). Hemicelluloses. *Ann. Rev. Plant Biol.*, 61, 263–289. <https://doi.org/10.1146/annurev-arplant-042809-112315>
150. Schneider, S. & Bergmann, L. (1995). Regulation of glutathione synthesis in suspension cultures of parsley and tobacco. *Bot. Acta*, 108(1), 34-40. <https://doi.org/10.1111/j.1438-8677.1995.tb00828.x>
151. Schützendübel, A. & Polle, A. (2002). Plant responses to abiotic stresses: heavy metal-induced oxidative stress and protection by mycorrhization. *J. Exp. Bot.*, 53(372), 1351–1365. <https://doi.org/10.1093/jexbot/53.372.1351>
152. Scoccianti, V., Bucchini, A.E., Iacobucci, M., Ruiz, K.B. & Biondi, S. (2016). Oxidative stress and antioxidant responses to increasing concentrations of trivalent chromium in the Andean crop species *Chenopodium quinoa* Willd. *Ecotoxicol. Environ. Saf.*, 133, 25–35. <https://doi.org/10.1016/j.ecoenv.2016.06.036>
153. Seleiman, M.F., Ali, S., Refay, Y., Rizwan, M., Alhammad, B.A. & El-Hendawy, S.E. (2020). Chromium resistant microbes and melatonin reduced Cr uptake and toxicity, improved physio-biochemical traits and yield of wheat in contaminated soil. *Chemosphere*, 250, 126239, 1-12. <https://doi.org/10.1016/j.chemosphere.2020.126239>
154. Sessitsch, A., Howieson, J.G., Perret, X., Antoun, H. & Martinez-Romero, E. (2002). Advances in Rhizobium research. *Crit. Rev. Plant Sci.*, 21(4), 323–378. <https://doi.org/10.1080/0735-260291044278>
155. Shahandeh, H. & Hossner, L.R. (2000). Plant screening for chromium phytoremediation. *Int. J. Phytorem.*, 2(1), 31-51. <https://doi.org/10.1080/15226510008500029>
156. Shahid, M., Pourrut, B., Dumat, C., Nadeem, M., Aslam, M. & Pinelli, E. (2014). Heavy metal induced reactive oxygen species: phytotoxicity and physicochemical changes in plants. *Rev. Environ. Contam. Toxicol.*, 232, 1-44. https://doi.org/10.1007/978-3-319-06746-9_1
157. Shahid, M., Shamshad, S., Rafiq, M., Khalid, S., Bibi, I., Niazi, N.K., Dumat, C. & Rashid, M.I. (2017). Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: A review. *Chemosphere*, 178, 513-533. <https://doi.org/10.1016/j.chemosphere.2017.03.074>
158. Shams, K.M., Tichy, G., Fische, A., Sager, M., Peer, T., Bashar, A. & Filip, K. (2010). Aspects of phytoremediation for chromium contaminated sites using common plants *Urtica dioica*, *Brassica napus* and *Zea mays*. *Plant Soil*, 328(1), 175-189. <https://doi.org/10.1007/s11104-009-0095-x>
159. Shanker, A.K., Cervantes, C. & Loza-Tavera H (2005). Chromium toxicity in plants. *Env. Int.*, 31(5), 739-753. <https://doi.org/10.1016/j.envint.2005.02.003>
160. Sharma, A., Kapoor, D., Wang, J., Shahzad, B., Kumar, V., Bali, A.S. & Yan, D. (2020). Chromium bioaccumulation and its impacts on plants: an overview. *Plants*, 9(1), 100. <https://doi.org/10.3390/plants9010100>
161. Sharma, A., Shahzad, B., Kumar, V., Kohli, S.K., Sidhu,

- G.P.S., Bali, A.S., Handa, N., Kapoor, D., Bhardwaj, R. & Zheng, B. (2019). Phytohormones regulate accumulation of osmolytes under abiotic stress. *Biomolecules*, 9 (7), 285. <https://doi.org/10.3390/biom9070285>
162. Sharma, P., Jha, A.B., Dubey, R.S. & Pessarakli, M. (2012). Reactive oxygen species, oxidative damage, and antioxidative defence mechanism in plants under stressful conditions. *J. Bot.*, 217037, 1-26. doi:10.1155/2012/217037
163. Sharma, R., Bhardwaj, R., Handa, N., Gautam, V., Kohli, S.K., Bali, S., Kaur, P., Thukral, A.K., Arora, S., Ohri, P. & Vig, A.P. (2016). Response of phytochelatin and metallothionein in alleviation of heavy metal stress in plants: an overview. *Plant Metal Interac.*, 263-277. <https://doi.org/10.1016/B978-0-12-803158-2.00010-2>
164. Shen, Z.J., Xu, D.C., Chen, Y.S. & Zhang, Z. (2017). Heavy metals translocation and accumulation from the rhizosphere soils to edible parts of medicinal plants Fengdan (*Peonia ostia*) grown on a metal mining area, China. *Ecotoxicol. Environ. Saf.*, 143, 19-37. <https://doi.org/10.1016/j.ecoenv.2017.04.042>
165. Sheng, X., He, L., Wang, Q., Ye, H. & Jiang, C. (2008). Effects of inoculation of biosurfactant-producing *Bacillus* sp. J119 on plant growth and cadmium uptake in a cadmium-amended soil. *J. Hazard. Mater.*, 155(1-2), 17-22. <https://doi.org/10.1016/j.jhazmat.2007.10.107>
166. Shukla, D., Tiwari, M., Tripathi, R.D., Nath, P. & Trivedi, P.K. (2013). Synthetic phytochelatin complement a phytochelatin deficient *Arabidopsis* mutant and enhance the accumulation of heavy metal(loid)s. *Biochem. Biophys. Res. Commun.*, 434(3), 664-669. <https://doi.org/10.1016/j.bbrc.2013.03.138>
167. Shukla, O.P., Juwarkar, A.A., Singh, S.K., Khan, S. & Rai, U.N. (2011). Growth responses and metal accumulation capabilities of woody plants during the phytoremediation of tannery sludge. *Waste Management*, 31(1), 115-123. <https://doi.org/10.1016/j.wasman.2010.08.022>
168. Singh, H.P., Mahajan, P., Kaur, S., Batish, D.R. & Kohli, R.K. (2013). Chromium toxicity and tolerance in plants. *Environ. Chem. Lett.*, 11(3), 229-254. <https://doi.org/10.1007/s10311-013-0407-5>
169. Singh, S., Parihar, P., Singh, R., Singh, V.P. & Prasad, S.M. (2016). Heavy metal tolerance in plants: role of transcriptomics, proteomics, metabolomics, and ionomics. *Front. Plant Sci.*, 6, 1143. <https://doi.org/10.3389/fpls.2015.01143>
170. Singh, S. & Prasad, S.M. (2019). Management of chromium (VI) toxicity by calcium and sulphur in tomato and brinjal: Implication of nitric oxide. *J. Hazard. Mater.*, 373, 212-223. <https://doi.org/10.1016/j.jhazmat.2019.01.044>
171. Singh, S., Prasad, S.M. & Singh, V.P. (2020). Additional calcium and sulphur manage hexavalent chromium toxicity in *Solanum lycopersicum* L. and *Solanum melongena* L. seedlings by involving nitric oxide. *J. Hazard. Mater.*, 122607, 1-11. <https://doi.org/10.1016/j.jhazmat.2020.122607>
172. Sinha, V., Pakshirajan, K. & Chaturvedi, R. (2018). Chromium tolerance, bioaccumulation and localization in plants: an overview. *J. Env.I Manage.*, 206, 715-730. <https://doi.org/10.1016/j.jenvman.2017.10.033>
173. Skeffington, R.A., Shewry, P.R. & Peterson, P.J. (1976). Chromium uptake and transport in barley seedlings (*Hordeum vulgare* L.). *Planta*, 132(3), 209-214. <https://doi.org/10.1007/BF00399719>
174. Smirnov, N. & Arnaud, D. (2019). Hydrogen peroxide metabolism and functions in plants. *New Phytol.*, 221(3), 1197-1214. <https://doi.org/10.1111/nph.15488>
175. Sobariu, D.L., Fertu, D.I.T., Diaconu, M., Pavel, L.V., Hlihor, R.M., Dragoi, E.N. & Gavrilescu, M. (2017). Rhizobacteria and plant symbiosis in heavy metal uptake and its implications for soil bioremediation. *New Biotech.*, 39, 125-134. <https://doi.org/10.1016/j.nbt.2016.09.002>
176. Somerville, C., Bauer, S., Brininstool, G., Facette, M., Hamann, T., Milne, J., Osborne, E., Paredes, A., Persson, S., Raab, T., Vorwerk, S. & Youngs, H. (2004). Toward a systems approach to understanding plant cell walls. *Science*, 306(5705), 2206-2211. DOI: 10.1126/science.1102765
177. Song, W.Y., Mendozacozatl, D.G., Lee, Y., Schroeder, J.I., AHN, S.N., Lee, H.S. & Martinoia, E. (2014). Phytochelatin-metal (loid) transport into vacuoles shows different substrate preferences in barley and *Arabidopsis*. *Plant Cell Env.*, 37(5), 1192-1201. <https://doi.org/10.1111/pce.12227>
178. Srivastava, S. & Thakur, I.S. (2012). Biosorption and biotransformation of chromium by *Serratia* sp. isolated from tannery effluent. *Env. Technol.*, 33(1), 113-122. <https://doi.org/10.1080/09593330.2011.551842>
179. Sultana, R., Islam, S.M.N., Zaman, M.W. & Uddin, N. (2020). Phytotoxicity of Lead and Chromium on Germination, Seedling Establishment and Metal Uptake by Kenaf and Mesta. *Pollution*, 6(2), 439-450. DOI: 10.22059/POLL.2020.293211.720
180. Sytar, O., Kumar, A., Latowski, D., Kuczynska, P., Strzałka, K. & Prasad, M.N.V. (2013). Heavy metal-induced oxidative damage, defence reactions, and detoxification mechanisms in plants. *Acta Physiol. Plant.*, 35(4), 985-999. <https://doi.org/10.1007/s11738-012-1169-6>
181. Taiz, L. & Zeiger, E. (2002). Solute transport. In: *Plant Physiology*. pp 87-99. Sinauer Associates. <https://doi.org/10.1007/s11104-013-1589-0>
182. Tangahu, B.V., Abdullah, S.R.S., Basri, H., Idris, M., Anuar, N. & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *Int. J. Chem. Engg.*, 2011: 1-31. <https://doi.org/10.1155/2011/939161>
183. Teixeira, J., Ferraz, P., Almeida, A., Verde, N. & Fidalgo, F. (2013). Metallothionein multigene family expression is differentially affected by Cr (III) and (VI) in *Solanum nigrum* L. plants. *Food Energy Sec.*, 2(2), 130-140. doi: 10.1002/fes3.26
184. Tiwari, K.K., Dwivedi, S., Singh, N.K., Rai, U.N. & Tripathi, R.D. (2009). Chromium (VI) induced phytotoxicity and oxidative stress in pea (*Pisum sativum* L.): biochemical changes and translocation of essential nutrients. *J. Environ. Biol.*, 30(3), 389-394.
185. Tomas, M., Pagani, M.A., Andreo, C.S., Capdevila, M., Atrian, S. & Bofill, R. (2015). Sunflower metallothionein family characterisation. Study of the Zn (II)- and Cd (II)-binding abilities of the HaMT1 and HaMT2 isoforms. *J. Inorg. Biochem.*, 148, 35-48. <https://doi.org/10.1016/j.jinorgbio.2015.02.016>

186. Tseng, C.H., Lee, I.H. & Chen, Y.C. (2019). Evaluation of hexavalent chromium concentration in water and its health risk with a system dynamics model. *Sci. Total Environ.*, 669, 103–111. <https://doi.org/10.1016/j.scitotenv.2019.03.103>
187. Tucker, M.R. & Koltunow, A.M. (2014). Traffic monitors at the cell periphery: the role of cell walls during early female reproductive cell differentiation in plants. *Curr. Opin. Plant Biol.*, 17, 137–145. <https://doi.org/10.1016/j.pbi.2013.11.015>
188. Turkan, I., Uzilday, B., Dietz, K.J., Brautigam, A. & Ozgur, R. (2018). Reactive oxygen species and redox regulation in mesophyll and bundle sheath cells of C4 plants. *J. Exp. Bot.*, 69(14), 3321–3331. <https://doi.org/10.1093/jxb/ery064>
189. Van Breusegem, F., Bailey-Serres, J. & Mittler, R. (2008). Unraveling the tapestry of networks involving reactive oxygen species in plants. *Plant Physiol.*, 147(3), 978–984. <https://doi.org/10.1104/pp.108.122325>
190. Van der Ent, A. & Reeves, R.D. (2015). Foliar metal accumulation in plants from copper-rich ultramafic outcrops: case studies from Malaysia and Brazil. *Plant Soil*, 389 (1–2), 401–418. <https://doi.org/10.1007/s11104-015-2385-9>
191. Verkleij, J.A.C., Sneller, F.E.C. & Schat, H. (2003). Metallothioneins and phytochelatins: ecophysiological aspects, In: Sulphur in Plants, 163–176. https://doi.org/10.1007/978-94-017-0289-8_9
192. Viti, C., Marchi, E., Decorosi, F. & Giovannetti, L. (2014). Molecular mechanisms of Cr (VI) resistance in bacteria and fungi. *FEMS Microbiol. Rev.*, 38(4), 633-659. <https://doi.org/10.1111/1574-6976.12051>
193. Vuletic, M., Hadsi-Taskovic Sukalovic, V., Markovic, K., Kravic, N., Vucinic, Z. & Maksimovic, V. (2014). Differential response of antioxidative systems of maize roots cell walls to osmotic and heavy metal stress. *Plant Biol.*, 16(1), 88–96. <https://doi.org/10.1111/plb.12017>
194. Wakeel, A., Xu, M. & Gan, Y. (2020) Chromium-induced reactive oxygen species accumulation by altering the enzymatic antioxidant system and associated cytotoxic, genotoxic, ultrastructural, and photosynthetic changes in plants. *Int. J. Mol. Sci.*, 21(3), 728. <https://doi.org/10.3390/ijms21030728>
195. Wang, J., Fen, X., Anderson, C.W.N., Xing, Y. & Shang, L. (2012). Remediation of mercury contaminated sites—A review. *J. Hazard. Mater.*, 221-222: 1–18. <https://doi.org/10.1016/j.jhazmat.2012.04.035>
196. Wani, P.A., Khan, M.S. & Zaidi, A. (2008). Effect of heavy metal toxicity on growth, symbiosis, seed yield and metal uptake in pea grown in metal amended soil. *Bull. Environ. Contam. Toxicol.*, 81(2), 152–158. <https://doi.org/10.1007/s00128-008-9383-z>
197. Waszczak, C., Carmody, M. & Kangasjärvi, J. (2018). Reactive oxygen species in plant signaling. *Ann. Rev. Plant Biol.*, 69, 209-236. <https://doi.org/10.1146/annurev-arplant-042817-040322>
198. Wei, L., Wang, K., Noguera, D.R., Jiang, J., Oyserman, B., Zhao, N. & Cui, F. (2016). Transformation and speciation of typical heavy metals in soil aquifer treatment system during long time recharging with secondary effluent: Depth distribution and combination. *Chemosphere*, 165, 100-109. <https://doi.org/10.1016/j.chemosphere.2016.09.027>
199. Wong, H.L., Sakamoto, T., Kawasaki, T., Umemura, K. & Shimamoto, K. (2004). Down-regulation of metallothionein, a reactive oxygen scavenger, by the small GTPase OsRac1 in rice. *Plant Physiol.*, 135, 1447–1456. <https://doi.org/10.1104/pp.103.036384>
200. Xia, X., Wu, S., Li, L., Xu, B. & Wang, G. (2018). The Cytochrome bd complex is essential for chromate and sulfide resistance and is regulated by a GbsR-type regulator, CydE, in *Alishewanella* sp. WH16-1. *Front. Microbiol.*, 9, 1849. <https://doi.org/10.3389/fmicb.2018.01849>
201. Xia, Y., Qi, Y., Yuan, Y., Wang, G., Cui, J., Chen, Y. & Shen, Z. (2012). Overexpression of Elsholtzia haichowensis metallothionein 1 (EhMT1) in tobacco plants enhances copper tolerance and accumulation in root cytoplasm and decreases hydrogen peroxide production. *J. Hazard. Mater.*, 233, 65-71. <https://doi.org/10.1016/j.jhazmat.2012.06.047>
202. Xie, X., He, Z., Chen, N., Tang, Z., Wang, Q. & Cai, Y. (2019). The roles of environmental factors in regulation of oxidative stress in plant. *BioMed Res. Int.*, 9732325. <https://doi.org/10.1155/2019/9732325>
203. Yadav, S. (2010). Heavy metals toxicity in plants: an overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. *South Afric. J. Bot.*, 76(2), 167–179. <https://doi.org/10.1016/j.sajb.2009.10.007>
204. Yang, J., Wang, Y., Liu, G., Yang, C. & Li, C. (2011). *Tamarix hispida* metallothionein-like ThMT3, a reactive oxygen species scavenger, increases tolerance against Cd²⁺, Zn²⁺, Cu²⁺, and NaCl in transgenic yeast. *Mol. Biol. Rep.*, 38(3), 1567–1574. <https://doi.org/10.1007/s11033-010-0265-1>
205. Yang, Z. & Chu, C. (2011). Towards understanding plant response to heavy metal stress. In *Abiotic Stress in Plants—Mechanisms and Adaptations* 59–78. DOI: 10.5772/24204
206. Yildiz, M., Terzi, H. & Bingul, N. (2013). Protective role of hydrogen peroxide pre-treatment on defence systems and BnMP1 gene expression in Cr (VI)-stressed canola seedlings. *Ecotoxicol.*, 22(8), 1303–1312. <https://doi.org/10.1007/s10646-013-1117-2>
207. Yilmaz, S.H., Kaplan, M., Temizgul, R. & Yilmaz, S. (2017). Antioxidant enzyme response of sorghum plant upon exposure to Aluminium, Cr and Lead heavy metals. *Turk. J. Biochem.*, 42(4), 503-512. <https://doi.org/10.1515/tjb-2016-0112>
208. You, S.H., Zhang, X.H., Liu, J., Zhu, Y.N. & Gu, C. (2014). Feasibility of constructed wetland planted with *Leersia hexandra* Swartz for removing Cr, Cu and Ni from electroplating wastewater. *Environ. Technol.*, 35, 187-194. <https://doi.org/10.1080/09593330.2013.822006>
209. Yu, X.Z., Gu, J.D. & Xing, L.Q. (2008). Differences in uptake and translocation of hexavalent and trivalent chromium by two species of willows. *Ecotoxicol.*, 17(8), 747-755. <https://doi.org/10.1007/s10646-008-0224-y>
210. Yu, X.Z., Lin, Y.J. & Zhang, Q. (2019). Metallothioneins enhance chromium detoxification through scavenging ROS and stimulating metal chelation in *Oryza sativa*. *Chemosphere*, 220, 300-313. <https://doi.org/10.1016/j.chemosphere.2018.12.119>
211. Yu, X.Z., Lu, C.J. & Li, Y.H. (2018). Role of cytochrome

- c in modulating chromium-induced oxidative stress in *Oryza sativa*. *Environ. Sci. Pollut. Res.*, 25(27), 27639-27649. <https://doi.org/10.1007/s11356-018-2817-1>
212. Yurekli, F. & Kucukbay, Z. (2003). Synthesis of phytochelatins in *Helianthus annuus* is enhanced by cadmium nitrate. *Acta Bot. Croat.*, 62(1), 21–25.
213. Zagorchev, L., Seal, C.E., Kranner, I.s. & Odjakova, M. (2013). A central role for thiols in plant tolerance to abiotic stress. *Int. J. Mol. Sci.*, 14(4), 7405–7432. <https://doi.org/10.3390/ijms14047405>
214. Zaheer, I.E., Ali, S., Rizwan, M., Abbas, Z., Bukhari, S.A.H., Wijaya, L., Alyemeni, M.N. & Ahmad, P. (2019). Zinc-lysine prevents chromium-induced morphological, photosynthetic, and oxidative alterations in spinach irrigated with tannery wastewater. *Environ. Sci. Pollut. Res.*, 26(28), 28951-28961. <https://doi.org/10.1007/s11356-019-06084-z>
215. Zaheer, I.E., Ali, S., Rizwan, M., Farid, M., Shakoor, M.B., Gill, R.A., Najeeb, U., Iqbal, N. & Ahmad, R. (2015). Citric acid assisted phytoremediation of copper by *Brassica napus* L. *Ecotoxicol. Environ. Saf.*, 120, 310–317. <https://doi.org/10.1016/j.ecoenv.2015.06.020>
216. Zaheer, I.E., Ali, S., Saleem, M.H., Imran, M., Alnusairi, G.S., Alharbi, B.M. & Soliman, M.H. (2020). Role of iron-lysine on morpho-physiological traits and combating chromium toxicity in rapeseed (*Brassica napus* L.) plants irrigated with different levels of tannery wastewater. *Plant Physiol. Biochem.*, 155, 70-84. <https://doi.org/10.1016/j.plaphy.2020.07.034>
217. Zeng, G., Jia, W., Huang, D., Liang, H., Chao, H., Min, C., Xue, W., Gong, X., Wang, R. & Jiang, D. (2017). Precipitation, adsorption and rhizosphere effect: the mechanisms for sphosphate-induced Pb immobilization in soils-a review. *J. Hazard. Mater.*, 339, 354–367. <https://doi.org/10.1016/j.jhazmat.2017.05.038>
218. Zewail, R.M., El-Desoukey, H.S. & Islam, K.R. (2020). Chromium stress alleviation by salicylic acid in Malabar spinach (*Basella alba*). *J. Plant Nutr.*, 43(9), 1268-1285. <https://doi.org/10.1080/01904167.2020.1727504>
219. Zhang, H., Guo, Q., Yang, J., Ma, J., Chen, G., Chen, T., Zhu, G., Wang, J., Zhang, G., Wang, X. & Shao, C. (2016). Comparison of chelates for enhancing *Ricinus communis* L. phytoremediation of Cd and Pb contaminated soil. *Ecotoxicol. Environ. Saf.*, 133, 57–62. <https://doi.org/10.1016/j.ecoenv.2016.05.036>
220. Zhao, Y.Y., Hu, C.X., Wang, X., Qing, X.J., Wang, P., Zhang, Y., Zhang, X. & Zhao, X.H. (2019). Selenium alleviated chromium stress in Chinese cabbage (*Brassica campestris* L.ssp. Pekinensis) by regulating root morphology and metal element uptake. *Ecotoxicol. Environ. Saf.*, 173, 314-321. <https://doi.org/10.1016/j.ecoenv.2019.01.090>
221. Zou, J., Yu, K., Zhang, Z., Jiang, W. & Liu, D. (2009). Antioxidant response system and chlorophyll fluorescence in chromium (VI)- treated *Zea Mays* L. seedlings. *Acta Biol. Crac. Ser. Bot.*, 51(1), 23–33.