

Contents

1	Heavy Metal Toxicity in Plants.	1
1.1	Heavy Metals: Nutrients or Toxic Elements?	1
1.2	Toxicity Mechanisms of Heavy Metals	3
1.3	Non-Essential Heavy Metals: Cadmium, Mercury, Lead, Chromium and Arsenic	5
1.3.1	Cadmium	5
1.3.2	Mercury	7
1.3.3	Lead	8
1.3.4	Chromium	9
1.3.5	Arsenic	11
1.4	Essential Metal Ions: Nickel, Copper, Iron, Manganese, Zinc, and Selenium	12
1.4.1	Nickel	12
1.4.2	Copper	14
1.4.3	Iron	14
1.4.4	Manganese	15
1.4.5	Zinc	16
1.4.6	Selenium	17
	References	19
2	Plant Responses to Heavy Metal Toxicity	27
2.1	Signal Transduction in Response to Heavy Metals.	28
2.1.1	The Ca-Calmodulin System	28
2.1.2	Hormones in the Heavy Metal Response	28
2.1.3	The Role of Reactive Oxygen Species	29
2.1.4	The MAPK Cascade	30
2.2	Metal Ion Uptake from Soil	30
2.2.1	Metal Ion Binding to Extracellular Exudates and to the Cell Wall	30

2.2.2	Metal Ion Transport through the Plasma Membrane in Root	31
2.2.3	Reduced Metal Uptake and Efflux Pumping at the Plasma Membrane.	33
2.3	Root-to-Shoot Metal Translocation	34
2.3.1	The HMA Family of Transporters.	35
2.3.2	The MATE Family of Efflux Proteins	35
2.3.3	The Oligopeptide Transporters Family.	35
2.4	Heavy Metal Chelation in the Cytosol	36
2.4.1	Phytochelatins	36
2.4.2	Metallothioneins and Ferritins	38
2.4.3	Organic Acids, Amino Acids, and Phosphate Derivatives.	39
2.5	Metal Sequestration in the Vacuole by Tonoplast Transporters	40
2.5.1	The ABC Transporters.	41
2.5.2	The CDF Transporters	41
2.5.3	The HMA Transporters	42
2.5.4	CaCA Transporters	42
2.5.5	NRAMP Transporters	43
2.6	Oxidative Stress Defence Mechanisms and the Repair of Stress-Damaged Proteins	43
	References	44
3	Plants that Hyperaccumulate Heavy Metals	55
3.1	Defining Hyperaccumulator Plants.	55
3.2	Ecological Role of Metal Hyperaccumulation in Plants	59
3.3	Determinants for Metal Hyperaccumulation	62
3.3.1	Metal Transporters	62
3.3.2	Metal Ligands	66
3.3.3	Response to Stress	67
	References	69
4	Phytoremediation: The Utilization of Plants to Reclaim Polluted Sites.	75
4.1	A Green Technology to Remove Heavy Metals from Soil and Water.	75
4.2	Plants Suitable for the Phytoremediation of Heavy Metals	76
4.3	Engineering Plant Metal Tolerance and Accumulation	77
4.3.1	Transgenic Plants Overexpressing Metal Transporter Proteins	78
4.3.2	Focusing on Metal Chemistry in Plants	79
4.3.3	Transgenic Plants Overexpressing Metal Chelating Compounds	81

4.4 Effects of Rhizosphere Microbes on Phytoremediation. 82

4.5 Perspectives 83

References 83