

## Contents

**List of Contributors XVII**

**Foreword XXV**

**Preface XXVII**

### **Part I Abiotic Stresses – An Overview 1**

<b>1</b>	<b>Abiotic Stress Signaling in Plants – An Overview 3</b>
	<i>Sarvajeet Singh Gill, Naser A. Anjum, Ritu Gill, and Narendra Tuteja</i>
1.1	Introduction 3
1.2	Perception of Abiotic Stress Signals 4
1.3	Abiotic Stress Signaling Pathways in Plants 4
1.3.1	Reactive Oxygen Species 5
1.3.2	Transcription Factors 6
1.3.3	Calcium and Calcium-Regulated Proteins 7
1.3.4	MAPK Cascades 7
1.4	Conclusions, Crosstalks, and Perspectives 8
	Acknowledgments 8
	References 9
<b>2</b>	<b>Plant Response to Genotoxic Stress: A Crucial Role in the Context of Global Climate Change 13</b>
	<i>Anca Macovei, Mattia Donà, Daniela Carbonera, and Alma Balestrazzi</i>
2.1	Introduction 13
2.2	Genotoxic Effects of UV Radiation 14
2.3	UV-B-Induced DNA Damage and Related Signaling Pathway 15
2.4	Repair of UV-B-Induced DNA Lesions: The Role of Photolyases 16
2.5	Contribution of the NER Pathway in the Plant Response to UV Radiation 17
2.6	Chromatin Remodeling and the Response to UV-Mediated Damage 18
2.7	Homologous Recombination and Nonhomologous End Joining Pathways are Significant Mechanisms in UV Tolerance 20

2.8	UV-B Radiation and Genotoxic Stress: <i>In Planta</i> Responses	21
2.9	Heat Stress: A Challenge for Crops in the Context of Global Climate Change	21
2.10	Conclusions	22
	References	23
<b>3</b>	<b>Understanding Altered Molecular Dynamics in the Targeted Plant Species in Western Himalaya in Relation to Environmental Cues: Implications under Climate Change Scenario</b>	<b>27</b>
	<i>Sanjay Kumar</i>	
3.1	Why Himalaya?	27
3.2	Climate Change is Occurring in Himalaya	31
3.3	Plant Response to Climate Change Parameters in Himalayan Flora	34
3.3.1	How to Enhance the Efficiency of Carbon Uptake? Plants at High Altitude Offer Clues	34
3.3.2	Managing Oxidative Stress the Nature's Way	36
3.3.2.1	Engineering SOD for Climate Change	37
3.3.3	Transcriptome Analysis Offers Genes and Gene Suits for Tolerance to Environmental Cues	37
3.3.3.1	Clues from Plants at High Altitude	38
3.3.3.2	Clues from Plants at Low Altitude	39
3.3.3.3	Summing up the Learning from Transcriptome Data	42
3.4	Impact on Secondary Metabolism under the Climate Change Scenario	42
3.5	Path Forward	46
	Acknowledgments	47
	References	48
<b>4</b>	<b>Crosstalk between Salt, Drought, and Cold Stress in Plants: Toward Genetic Engineering for Stress Tolerance</b>	<b>55</b>
	<i>Sagarika Mishra, Sanjeev Kumar, Bedabrata Saha, Jayprakash Awasthi, Mohitosh Dey, Sanjib Kumar Panda, and Lingaraj Sahoo</i>	
4.1	Introduction	56
4.2	Signaling Components of Abiotic Stress Responses	57
4.3	Decoding Salt Stress Signaling and Transduction Pathways	58
4.3.1	Signal Perception, Sensors, and Signaling in Plant Cells	59
4.3.1.1	Calcium: An Active Sensor for Salt Stress	59
4.3.1.2	Role of IP3 in Signaling Events for Salt Stress	59
4.3.1.3	SOS Pathway – A Breakthrough Approach in Deciphering Salt Signaling	60
4.3.1.4	Role of pH in Salt Stress Signaling	61
4.3.1.5	ABA Signaling in Salt Stress	61
4.3.1.6	ROS Accumulation in Salt Stress	61
4.4	Drought Stress Signaling and Transduction Pathways	62

4.4.1	Drought Stress Sensors	63
4.4.1.1	Histidine Kinases (HKs)	63
4.4.1.2	Receptor-Like Kinases (RLK)	64
4.4.1.3	Microtubules as Sensors	65
4.4.2	Drought Signal Transduction	65
4.4.2.1	ABA-Dependent Pathway	66
4.4.2.2	Drought Signal Effector	67
4.5	Cold Stress Signaling and Transduction Pathways	68
4.5.1	Cold Stress Sensors	68
4.5.2	Signal Transduction	69
4.5.2.1	ABA-Independent Pathway Involved in Cold and Drought Stress Responses	69
4.5.2.2	Role of Transcription Factors/Element	70
4.5.3	Cold Stress Effector	72
4.5.3.1	HSF/HSP	72
4.5.3.2	ROS	72
4.6	Transgenic Approaches to Overcome Salinity Stress in Plants	73
4.6.1	MYB-Type Transcription Factors	73
4.6.2	Zinc Finger Proteins	74
4.6.3	NAC-Type Transcription Factors	74
4.6.4	bZIP (Basic Leucine Zipper) Transcription Factors	74
4.6.5	MAPKs (Mitogen-Activated Protein Kinases)	75
4.6.6	CDPKs (Calcium-Dependent Protein Kinases)	75
4.6.7	RNA-Interference-Mediated Approach and Role of siRNAs and miRNAs in Developing Salt-Tolerant Plants	75
4.7	Conclusion	76
	References	77
5	<b>Intellectual Property Management and Rights, Climate Change, and Food Security</b>	87
	<i>Karim Maredia, Frederic Erbisch, Callista Rakhmatov, and Tom Herlache</i>	
5.1	Introduction: What Are Intellectual Properties?	88
5.2	Protection of Biotechnologies	88
5.2.1	Federal Protection	88
5.2.1.1	Patents	88
5.2.1.2	Plant Variety Protection	89
5.2.1.3	Copyright	90
5.2.1.4	Trademarks	90
5.2.2	Non-federal Protection	91
5.2.2.1	Material Transfer Agreements (MTA)	91
5.2.2.2	Confidential Disclosure Agreements (CDA)	91
5.2.2.3	Research Agreements	91
5.2.2.4	Cooperative or Inter-Institutional Agreements	92
5.3	Management Challenges of Biotechnologies	92

5.3.1	Recognizing the Value of Intellectual Property	92
5.3.2	Creating General Awareness of the Importance of Intellectual Property and Intellectual Property Rights (IPR)	93
5.3.3	Developing an Intellectual Property Management System/Focal Point	93
5.3.4	Building Functional National and Institutional Intellectual Property Policies	93
5.3.5	Enforcement/Implementation of Intellectual Property Policies	93
5.3.6	Institutional Support and Commitment	94
5.4	Making Biotechnologies Available	94
5.5	Licensing of Biotechnologies	95
5.6	Intellectual Property Management and Technology Transfer System at Michigan State University	96
5.7	IP Management and Technology Transfer at Michigan State University	96
5.8	Enabling Environment for IP Management, Technology Transfer, and Commercialization at MSU	97
5.9	International Education, Training and Capacity Building Programs in IP Management and Technology Transfer	99
5.10	Impacts of MSU's IP Management and Technology Transfer Capacity Building Programs	100
5.11	Summary and Way Forward	102
	References	103

**Part II      Intracellular Signaling 105**

<b>6</b>	<b>Abiotic Stress Response in Plants: Role of Cytoskeleton</b>	<b>107</b>
	<i>Neelam Soda, Sneha L. Singla-Pareek, and Ashwani Pareek</i>	
6.1	Introduction	107
6.1.1	Cytoskeleton in Prokaryotes	108
6.1.1.1	FtsZ	109
6.1.1.2	MreB and ParM	109
6.1.1.3	Crescentin	109
6.1.2	Cytoskeleton in Eukaryotes	109
6.1.2.1	Microtubules	109
6.1.2.2	Microfilaments	109
6.1.2.3	Intermediate Filament	110
6.1.2.4	Microtrabeculae	111
6.2	Role of Cytoskeleton in Cells	111
6.3	Abiotic Stress-Induced Structural Changes in MTs	112
6.4	Abiotic Stress-Induced Structural Changes in MFs	116
6.5	Abiotic Stress-Induced Structural Changes in Intermediate Filaments	119
6.6	Abiotic Stress and Cytoskeletal Associated Proteins	119
6.7	Future Perspectives	121

	Acknowledgments	122
	References	122
<b>7</b>	<b>Molecular Chaperone: Structure, Function, and Role in Plant Abiotic Stress Tolerance</b>	<b>131</b>
	<i>Dipesh Kumar Trivedi, Kazi Md. Kamrul Huda, Sarvajeet Singh Gill, and Narendra Tuteja</i>	
7.1	Introduction	131
7.2	Heat Shock Proteins	133
7.2.1	Structure and Function	133
7.2.2	Role of Heat Shock Proteins in Abiotic Stress Tolerance in Plants	136
7.3	Calnexin/Calreticulin	138
7.3.1	Introduction	138
7.3.2	Mechanism of Calnexin/Calreticulin	139
7.3.3	Responses against Abiotic Stresses	140
7.3.4	Activation in Response Misfolded Protein	140
7.4	Cyclophilin and Protein Disulfide Isomerase	140
7.5	Other Reports Regarding Molecular Chaperones	142
7.6	Conclusion and Future Outlook	143
	Acknowledgment	143
	References	144
<b>8</b>	<b>Physiological Roles of Glutathione in Conferring Abiotic Stress Tolerance to Plants</b>	<b>151</b>
	<i>Kamrun Nahar, Mirza Hasanuzzaman, and Masayuki Fujita</i>	
8.1	Introduction	152
8.2	Biosynthesis and Metabolism of Glutathione	153
8.3	Roles of Glutathione under Abiotic Stress Conditions	154
8.3.1	Salinity	155
8.3.2	Drought	160
8.3.3	Toxic Metals	161
8.3.4	Extreme Temperature	163
8.3.5	Ozone	164
8.4	Glutathione and Oxidative Stress Tolerance	165
8.4.1	Direct Role of Glutathione as Antioxidant	165
8.4.2	Role of Glutathione in Regulation of Its Associated Antioxidant Enzymes	166
8.5	Involvement of Glutathione in Methylglyoxal Detoxification System	167
8.6	Role of Glutathione as a Signaling Molecule under Abiotic Stress Condition	169
8.7	Conclusion and Future Perspective	171
	Acknowledgments	171
	References	171

<b>9</b>	<b>Role of Calcium-Dependent Protein Kinases during Abiotic Stress Tolerance</b>	<b>181</b>
	<i>Tapan Kumar Mohanta and Alok Krishna Sinha</i>	
9.1	Introduction	181
9.2	Classification of CDPKs	182
9.3	Substrate Recognition	184
9.4	Mechanism of Regulation of CDPKs	185
9.4.1	Ca <sup>2+</sup> -Mediated Regulation	187
9.4.2	Regulation by Autophosphorylation	188
9.4.3	Hormonal Regulation of CDPKs	188
9.4.4	Reactive Oxygen Species (ROS)-Mediated Regulation	190
9.5	Subcellular Localization of CDPKs	190
9.6	Crosstalk between CDPKs and MAPKs	191
9.7	CDPK in Stress Response	193
9.7.1	Rice CDPK in Stress Response	193
9.7.2	Arabidopsis CDPK in Stress Response	194
9.7.3	Wheat CDPK in Stress Response	195
9.8	Conclusion	196
	Abbreviations	197
	References	197
<b>10</b>	<b>Lectin Receptor-Like Kinases and Their Emerging Role in Abiotic Stress Tolerance</b>	<b>203</b>
	<i>Neha Vaid, Prashant K. Pandey, and Narendra Tuteja</i>	
10.1	Introduction	203
10.2	Evolution of RLKs	205
10.3	Lectin Receptor-Like Kinase	206
10.4	Classification of the LecRLK Family	206
10.5	Roles of LecRLKs	207
10.5.1	Role in Abiotic Stress Tolerance	209
10.5.2	Roles of LecRLKs in Development and Biotic Stresses	210
10.6	Conclusion	210
	Acknowledgments	212
	References	212
	<b>Part III      Extracellular or Hormone-Based Signaling</b>	<b>217</b>
<b>11</b>	<b>Heavy-Metal-Induced Oxidative Stress in Plants: Physiological and Molecular Perspectives</b>	<b>219</b>
	<i>Sanjib Kumar Panda, Shuvavish Choudhury, and Hemanta Kumar Patra</i>	
11.1	Background and Introduction	219
11.2	ROS and Oxidative Stress: Role of Heavy Metals	222
11.3	Heavy-Metal Hyperaccumulation and Hypertolerance	223
11.4	Molecular Physiology of Heavy-Metal Tolerance in Plants	224

11.5	Future Perspectives 226
	References 227
<b>12</b>	<b>Metallothioneins and Phytochelatins: Role and Perspectives in Heavy Metal(lod) Stress Tolerance in Crop Plants 233</b>
	<i>Devesh Shukla, Prabodh K. Trivedi, Pravendra Nath, and Narendra Tuteja</i>
12.1	Introduction 233
12.1.1	Essential Heavy Metals 234
12.1.2	Nonessential Heavy Metals 234
12.1.2.1	Cadmium 235
12.1.2.2	Arsenic 235
12.2	Methods/Processes of Remediation of Soil 236
12.2.1	Heavy-Metal Tolerance and Remediation by Plants 236
12.3	Metal-Binding Ligands of Plants 238
12.3.1	Metallothioneins 238
12.3.1.1	General Classification of MTs 239
12.3.1.2	Function of Metallothioneins 241
12.3.1.3	Overexpression of Metallothioneins in Plants and Other Organisms 242
12.3.2	Phytochelatins 244
12.3.2.1	General Structure and Function of Phytochelatins 244
12.3.2.2	Biosynthesis of Phytochelatins 245
12.3.2.3	Cloning of <i>Phytochelatin Synthase</i> Gene 248
12.3.2.4	Expression of PC Synthase in Plants 250
12.3.2.5	Expression of PC Synthase in Transgenic Organisms Leads to Contradictory Results 251
12.3.2.6	Application of Phytochelatin in Phytoremediation 254
12.3.2.7	Artificial PCs, a Synthetic Biology Approach toward Phytoremediation 254
12.4	Conclusion 255
	Acknowledgments 256
	Abbreviations 256
	References 256
<b>13</b>	<b>Plant Response to Arsenic Stress and Role of Exogenous Selenium to Mitigate Arsenic-Induced Damages 261</b>
	<i>Meetu Gupta, Chandana Pandey, and Shikha Gupta</i>
13.1	Introduction 262
13.1.1	Arsenic and Selenium 262
13.1.2	Arsenic and Selenium Interaction 263
13.2	Arsenic and Selenium in Food Crop Plants 265
13.2.1	Biofortification 266
13.3	Role of Signaling Molecules in Mitigation of Arsenic and Selenium 267

13.4	Conclusion and Future Perspectives	270
	References	271
<b>14</b>	<b>Brassinosteroids: Physiology and Stress Management in Plants</b>	275
	<i>Geetika Sirhind, Manish Kumar, Sandeep Kumar, and Renu Bhardwaj</i>	
14.1	Background and Introduction	275
14.2	Physiological Roles of BRs	277
14.2.1	Seed Germination	277
14.2.2	BRs in Cell Division, Elongation, and Tissue Differentiation	278
14.2.3	BRs in Shoot and Root Development	279
14.2.4	BR in Flowering and Fruit Development	281
14.2.5	Brassinosteroids in Stress Management	283
14.2.6	Brassinosteroids in Biotic Stress Tolerance	284
14.3	Brassinosteroids in Abiotic Stress Tolerance	286
14.3.1	Water Stress	286
14.3.2	Salinity Stress	288
14.3.3	BR in Heavy-Metal Stress	291
14.3.4	BR in Chilling Stress	294
14.3.5	BR in Heat Stress	295
14.4	Conclusion	297
	References	297
<b>15</b>	<b>Abscisic Acid (ABA): Biosynthesis, Regulation, and Role in Abiotic Stress Tolerance</b>	311
	<i>Dipesh Kumar Trivedi, Sarvajeet Singh Gill, and Narendra Tuteja</i>	
15.1	Introduction	311
15.2	Abscisic Acid Biosynthesis and Signaling	312
15.3	Abscisic Acid and Transcription Factors in Abiotic Stress Tolerance	312
15.4	Abiotic Stress Tolerance Mediated by Abscisic Acid	315
15.5	Conclusion and Future Outlook	318
	Acknowledgments	318
	References	318
<b>16</b>	<b>Cross-Stress Tolerance in Plants: Molecular Mechanisms and Possible Involvement of Reactive Oxygen Species and Methylglyoxal Detoxification Systems</b>	323
	<i>Mohammad Anwar Hossain, David J. Burritt, and Masayuki Fujita</i>	
16.1	Introduction	324
16.2	Perception of Heat- and Cold-Shock and Response of Plants	326
16.3	Reactive Oxygen Species Formation under Abiotic Stress in Plants	329
16.4	Reactive Oxygen Species Scavenging and Detoxification System in Plants	332

16.5	Antioxidant Defense Systems and Cross-Stress Tolerance of Plants	332
16.6	Methylglyoxal Detoxification System (Glyoxalase System) in Plant Abiotic Stress Tolerance and Cross-Stress Tolerance	338
16.7	Signaling Roles for Methylglyoxal in Induced Plant Stress Tolerance	340
16.8	The Involvement of Antioxidative and Glyoxalase Systems in Cold- or Heat-Shock-Induced Cross-Stress Tolerance	341
16.9	Hydrogen Peroxide ( $H_2O_2$ ) and Its Role in Cross-Tolerance in Plants	343
16.10	Regulatory Role of $H_2O_2$ during Abiotic Oxidative Stress Responses and Tolerance	344
16.11	$H_2O_2$ : A Part of Signaling Network	349
16.12	Involvement of Heat- or Cold-Shock Protein (HSP or CSP) Chaperones	350
16.13	Amino Acids (Proline and GB) in Abiotic Stress Tolerance and Cross-Stress Tolerance	354
16.14	Involvement of $Ca^{+2}$ and Plant Hormones in Cross-Stress Tolerance	357
16.15	Conclusion and Future Perspective	358
	Acknowledgments	359
	Abbreviations	359
	References	359

#### **Part IV Translational Plant Physiology 377**

17	<b>Molecular Markers and Crop Improvement</b>	379
	<i>Brijmohan Singh Bhau, Debojit Kumar Sharma, Munmi Bora, Sneha Gosh, Sangeeta Puri, Bitupon Borah, Dugganaboyana Guru Kumar, and Sawlang Borsingh Wann</i>	
17.1	Introduction	380
17.1.1	Importance of Crop Improvement	382
17.1.2	Environmental Constraints Limiting Productivity	383
17.1.3	High Temperatures	385
17.1.4	Drought	385
17.1.5	Salinity	386
17.1.6	Flooding	387
17.1.7	Role of Modern Biotechnology	388
17.2	Molecular Markers	391
17.2.1	Improved or "Smart" Crop Varieties	394
17.2.2	Molecular Plant Breeding and Genetic Diversity for Crop Improvement	395
17.3	Conclusion	397
	References	400

<b>18</b>	<b>Polyamines in Stress Protection: Applications in Agriculture</b>	<b>407</b>
	<i>Rubén Alcázar and Antonio F. Tiburcio</i>	
18.1	Challenges in Crop Protection against Abiotic Stress: Contribution of Polyamines	407
18.2	Polyamine Homeostasis: Biosynthesis, Catabolism and Conjugation	409
18.3	Drought Stress and PA Metabolism	411
18.4	Polyamine Metabolism in Drought-Tolerant Species	413
18.5	Regulation of PA Metabolism by ABA	414
18.6	Future Perspectives	415
	Acknowledgments	416
	References	416
	<b>Index</b>	<b>419</b>