Contents to Volume 1

Preface XXIX
List of Contributors XXXIII

Part One Climate Change 1

1 Climate Change: Challenges for Future Crop Adjustments 3
Jerry L. Hatfield
1.1 Introduction 3
1.2 Climate Change 4
1.3 Crop Responses to Climate Change 7
1.3.1 Temperature Responses 7
1.3.1.1 Annual Crops 7
1.3.1.2 Major Challenges 11
1.4 Water Responses 11
1.5 Major Challenges 17
1.5.1 Growth and Development Processes and WUE 17
1.5.2 Growth and Development Processes Linked to Quality 18
1.6 Grand Challenge 19
References 19

2 Developing Robust Crop Plants for Sustaining Growth and Yield Under Adverse Climatic Changes 27
Vijaya Shukla and Autar K. Mattoo
2.1 Introduction 27
2.2 Elevated Temperature and Plant Response 29
2.3 Elevated CO₂ Levels and Plant Response 30
2.4 Genetic Engineering Intervention to Build Crop Plants for Combating Harsh Environments 30
2.4.1 Transcription Factors 31
2.4.2 bZIP Transcription Factors 35
2.4.3 DREB/ERF Transcription Factors 36
2.4.4 MYB Transcription Factors 37
3 Climate Change and Abiotic Stress Management in India 57
   R.B. Singh
   3.1 Introduction 57
   3.2 Impact of Climate Change and Associated Abiotic Stresses on Agriculture 59
      3.2.1 Trend of Change and Impact on Agricultural Production 59
      3.2.2 Impact on Water and Soil 62
         3.2.2.1 Water 62
         3.2.2.2 Soil 63
   3.3 CSA: Technologies and Strategies 63
      3.3.1 Sustainable Productivity Enhancement 63
      3.3.2 Adaptation 64
         3.3.2.1 Rice–Wheat System 65
         3.3.2.2 Stress-Tolerant Varieties 66
   3.4 National Initiative on Climate Resilient Agriculture 67
      3.4.1 Mitigation 69
   3.5 Policy and Institutions 72
      3.5.1 Mainstreaming CSA in National Policy 72
      3.5.2 CSV 74
      3.5.3 Agricultural Insurance and Risk Management 74
      3.5.4 Information and Communication Technology for Climate Change Management 75
   3.6 Partnership 75
   References 77

Part Two Abiotic Stress Tolerance and Climate Change 79

4 Plant Environmental Stress Responses for Survival and Biomass Enhancement 81
   Yuriko Osakabe, Keishi Osakabe, and Kazuo Shinozaki
   4.1 Introduction 81
   4.2 Stomatal Responses in the Control of Plant Productivity 82
      4.2.1 ABA Biosynthesis and Transport 83
4.2.2 Signal Mediation of Stomatal Aperture 84
4.2.3 Guard Cell Development 86
4.3 Signaling and Transcriptional Control in Water Stress Tolerance 87
4.3.1 Signaling Mediation by Membrane-Localized Proteins 87
4.3.2 Stress-Responsive Transcription 90
4.3.3 Key Transcription Factors 91
4.4 Protection Mechanisms of Photosynthesis During Water Stress 92
4.5 Metabolic Adjustment During Water Stress 94
4.5.1 Metabolomic Study of Primary Metabolites 94
4.5.2 Cell Wall Compounds 95
4.6 Future Perspective 96
References 97

5 Heat Stress and Roots 109
Scott A. Heckathorn, Anju Giri, Sasmita Mishra, and Deepesh Bista
5.1 Roots, Heat Stress, and Global Warming: An Overview of the Problem 109
5.2 Effects of Heat Stress on Root Growth and Root versus Shoot Mass and Function 111
5.2.1 Root Growth 116
5.2.2 Effects of Heat Stress on Roots versus Shoots 119
5.2.3 Shoot and Root versus Root-Only versus Shoot-Only Heating 119
5.2.4 Chronic versus Acute Heat Stress 121
5.2.5 Direct versus Indirect Effects of Heat Stress on Roots and Shoots 122
5.2.6 Effects of Heat Stress on Nutrient Relations 123
5.2.7 Effects of Heat Stress on Root Respiration and Carbon Metabolism 125
5.2.8 Effects of Heat Stress on Root Water Relations 126
5.3 Interactions Between Heat Stress and Other Global Environmental-Change Factors on Roots 126
5.4 Heat Stress and Root–Soil Interactions 128
5.5 Summary: Synthesizing What We Know and Predict into a Conceptual Model of Heat Effects on Roots and Plant–Soil Links 129
References 131

6 Role of Nitrosative Signaling in Response to Changing Climates 137
Panagiota Filippou, Chrystalla Antoniou, and Vasileios Fotopoulos
6.1 Introduction 137
6.2 Salinity 138
6.3 Drought 142
6.4 Heavy Metals 146
6.5 Heat Stress 148
6.6 Chilling/Freezing/Low Temperature 150
6.7 Anoxia/Hypoxia 151
9 **Drought Stress Responses in Plants, Oxidative Stress, and Antioxidant Defense** 209

*Mirza Hasanuzzaman, Kamrun Nahar, Sarvajeet Singh Gill, and Masayuki Fujita*

9.1 Introduction 210
9.2 Plant Response to Drought Stress 211
9.2.1 Germination 211
9.2.2 Plant Growth 214
9.2.3 Plant–Water Relations 216
9.2.4 Stomatal Conductance and Gas Exchange 217
9.2.5 Photosynthesis 219
9.2.6 Reproductive Development and Seed Formation 223
9.2.7 Yield Attributes and Yield 226
9.3 Drought and Oxidative Stress 229
9.4 Antioxidant Defense System in Plants Under Drought Stress 232
9.4.1 Non-Enzymatic Components 233
9.4.2 Enzymatic Components 234
9.5 Conclusion and Future Perspectives 236

References 237

10 **Plant Adaptation to Abiotic and Genotoxic Stress: Relevance to Climate Change and Evolution** 251

*Brahma B. Panda, V. Mohan M. Achary, Srikrishna Mahanty, and Kamal K. Panda*

10.1 Introduction 251
10.2 Plant Responses to Abiotic Stress 252
10.3 ROS Induce Genotoxic Stress 256
10.4 Adaptive Responses to Oxidative Stress 257
10.5 Transgenic Adaptation to Oxidative Stress 260
10.6 Adaptive Response to Genotoxic Stress 260
10.7 Role of MAPK and Calcium Signaling in Genotoxic Adaptation 267
10.8 Role of DNA Damage Response in Genotoxic Adaptation 269
10.9 Epigenetics of Genotoxic Stress Tolerance 272
10.10 Transgenerational Inheritance and Adaptive Evolution Driven by the Environment 274
10.11 Concluding Remarks 278

References 278

11 **UV-B Perception in Plant Roots** 295

*Ken Yokawa and František Baluška*

11.1 Introduction 295
11.2 Effect of UV-B on Plants 296
11.2.1 UV-Mediated ROS Generation 296
11.2.2 Response of Plant Roots to Light of a Broad Wavelength 297
11.2.3 UV-B Receptors Found in Roots 298
11.2.4 Tryptophan in UV-B Perception 299
11.2.5 Root Evolution Under a UV-B Environment 299
11.3 Land Plant Evolution was Shaped via Ancient Ozone Depletion 301
References 302

12 Improving the Plant Root System Architecture to Combat Abiotic Stresses Incurred as a Result of Global Climate Changes 305
Ananda K. Sarkar, Karthikeyan Mayandi, Vibhav Gautam, Suvakanta Barik, and Shabari Sarkar Das
12.1 Introduction 305
12.2 RSA and its Basic Determinants 306
12.3 Breeding Approaches to Improve RSA and Abiotic Stress Tolerance 308
12.3.1 Conventional Breeding Approach 308
12.3.2 Identification of QTLs Associated with Specific RSA Traits and Stress Tolerance 309
12.4 Genomic Approaches to Identify Regulators of RSA Associated with Abiotic Stress Tolerance 311
12.5 Transgenic Approaches to Improve RSA for Abiotic Stress Tolerance 313
12.6 Use of Polyamines and Osmotic Regulators in Stress-Induced Modulation of RSA 314
12.7 Hormonal Regulation of Root Architecture and Abiotic Stress Response 315
12.8 Small RNA-Mediated Regulation of RSA and Abiotic Stress Response 317
12.9 Application of Phenomics in Understanding Stress-Associated RSA 319
12.10 Conclusion and Future Perspectives 320
References 321

13 Activation of the Jasmonate Biosynthesis Pathway in Roots in Drought Stress 325
Palmiro Poltronieri, Marco Taurino, Stefania De Domenico, Stefania Bonsegna, and Angelo Santino
13.1 Background and Introduction 325
13.2 Plant Growth Factors: Key Role in Biotic and Abiotic Stress Signaling 326
13.3 Jasmonate Biosynthesis Pathway 328
13.4 Roots as the Primary Organ Sensing the Soil Environment 330
13.5 Symbiotic Microorganisms Affect Root Growth and Plant Performance 331
13.6 Symbiotic Organisms Alleviate and Improve Abiotic Stress Tolerance of Host Plants 332
13.7 Role of Jasmonates in Roots 333
13.8 Jasmonic Acid Signal Transduction in Roots and Jasmonic Acid Involvement in Abiotic Stress Response 333
13.9 Jasmonate in Root Response to Abiotic Stresses: Model Legumes and Chickpea Tolerant Varieties Showing Differential Transcript Expression During Salt and Drought Stress 334
13.10 Role of Transcription Factors and MicroRNAs in the Regulation of Jasmonic Acid Signaling 336
13.11 Conclusion 338

References 338

Contents to Volume 2

List of Contributors XXV

Part Three Approaches for Climate Change Mitigation 343

14 Can Carbon in Bioenergy Crops Mitigate Global Climate Change? 345

Abdullah A. Jaradat

14.1 Introduction 345
14.2 The Many Faces of Carbon 348
14.2.1 Carbon: A Scarce Commodity 349
14.2.2 Carbon and Nitrogen Cycles 350
14.3 Are Bioenergy Crops Carbon-Neutral? 352
14.4 Recalcitrant Carbon in Bioenergy Crops 354
14.5 Climate Change Mitigation Potential of Bioenergy Crops 355
14.5.1 Biomass versus Bioenergy Density 358
14.5.2 Temporal Changes of Carbon in the Soil–Bioenergy Crops–Atmosphere Continuum 360
14.6 Carbon in Bioenergy Crops 361
14.6.1 Carbon in Traditional Bioenergy Plants 362
14.6.2 Carbon in First-Generation Bioenergy Crops 363
14.6.3 Carbon in Second-Generation Bioenergy Crops 364
14.6.4 Carbon in Third-Generation Bioenergy Crops 367
14.7 Genetic Improvement of Bioenergy Crops 369
14.7.1 Genetics, Breeding, Transgenics, and Carbon Sequestration 370
14.7.2 Genetic Models and Ideotypes of Bioenergy Crops 373
14.8 Carbon Management in Bioenergy Crops 374
14.8.1 Managing Carbon Sources and Sinks 375
14.8.2 Managing Nutrient Composition, Cycling, and Loss 377
14.8.3 Managing Land-Use Change 379
14.8.4 Biogeochemical Liabilities of Carbon in Bioenergy Crops 381
14.9 Carbon Quality in Bioenergy Crops 383
14.10 Life Cycle Assessment 385
14.11 Ecosystem Services of Carbon in Bioenergy Crops 387
14.12 Eco-Physiology and Carbon Sequestration 389
14.13 Climate Ethics and Carbon in Bioenergy Crops 391
14.13.1 Biofuel versus Food 392
14.13.2 Biofuel versus Water 394
14.13.3 Biofuel versus Biodiversity 397
14.15 Conclusions 403
References 405

15 Adaptation and Mitigation Strategies of Plant Under Drought and High-Temperature Stress 421
Pasala Ratna Kumar, Susheel Kumar Raina, Satish Kumar, Kiran P. Bhagat, Yogeshwar Singh, and Santanu Kumar Bal
15.1 Background and Introduction 421
15.2 Plant Molecular Adaptation and Strategies Under Drought Stress 422
15.2.1 Transcription Factors 424
15.2.2 Small RNAs 425
15.2.3 Involvement of Polyamines in Abiotic Stress Tolerance in Plants 425
15.2.4 Role of Microorganisms in Plant Drought Stress Tolerance 426
15.3 Plant Adaptation and Mitigation Strategies for Heat Stress Tolerance 427
15.3.1 Thermal Stability of Cell Membranes 429
15.3.2 HSPs 429
15.3.3 Other Thermotolerance Factors 431
15.4 Conclusions 433
References 433

16 Emerging Strategies to Face Challenges Imposed by Climate Change and Abiotic Stresses in Wheat 437
Bharti Garg, Shreelekha Misra, and Narendra Tuteja
16.1 Introduction 437
16.2 Physiological and Molecular Adaptive Strategies in Wheat 438
16.3 Drought Tolerance 440
16.4 Salinity Tolerance 444
16.5 Heat Tolerance 445
16.6 Cold Tolerance 447
16.7 Functional and Comparative Genomics Approaches for Wheat Improvement 449
16.8 Conclusion and Future Perspectives 450
References 452
## 17 Protein Structure–Function Paradigm in Plant Stress Tolerance 459
*Harshesh Bhatt, Anil Kumar, and Neel Sarovar Bhavesh*

17.1 Introduction 459  
17.2 Plant Signaling Machinery 460  
17.3 Proteins Involved in Metabolic Regulation 465  
17.4 Stabilization of Proteins and RNAs 469  
17.5 Antifreeze Proteins 472  
17.6 Disordered Stress Proteins 473  
17.7 Summary 473  
References 474

## 18 Abiotic Stress-Responsive Small RNA-Mediated Plant Improvement Under a Changing Climate 481
*Basel Khraiwesh and Enas Qudeimat*

18.1 Introduction 481  
18.2 Classes of Small RNAs 483  
18.2.1 miRNAs 483  
18.2.1.1 Biogenesis of miRNAs 483  
18.2.1.2 Role of miRNAs in Plant Stress Responses for Adapting to Climate Change 486  
18.2.2 siRNAs 492  
18.2.2.1 Biogenesis of siRNAs 492  
18.2.2.2 Role of siRNAs in Plant Stress Responses for Adapting to Climate Change 492  
18.3 Artificial miRNAs 494  
18.4 Stress–miRNA Networks for Adapting to Climate Change 494  
18.5 Application of Small RNA-Mediated Suppression Approaches for Plant Improvement Under a Changing Climate 497  
18.6 Conclusions and Outlook 499  
Note 500  
References 500

## 19 Impact of Climate Change on MicroRNA Expression in Plants 507
*Vallabhi Ghorecha, N.S.R. Krishnayya, and Ramanjulu Sunkar*

19.1 Introduction 507  
19.2 Small Non-Coding RNAs in Plants 508  
19.3 Biogenesis and Function of miRNAs in Plants 509  
19.4 Heat Stress 511  
19.5 Drought 513  
19.6 UV-B Radiation 514  
19.7 Ozone 515  
19.8 Conclusions and Future Directions 515  
References 517
20  Role of Abscisic Acid Signaling in Drought Tolerance and Preharvest Sprouting Under Climate Change  521
Yasunari Fujita, Kazuo Nakashima, Takuya Yoshida, Miki Fujita, Kazuo Shinozaki, and Kazuko Yamaguchi-Shinozaki
20.1  Introduction  521
20.2  Major ABA Signaling Components in Response to Cellular Dehydration  522
20.2.1  Perception of ABA by the PYR/PYL/RCAR–PP2C–ABA Receptor Complex  524
20.2.2  Subclass III SnRK2s are Major Positive Regulators in Osmotic Stress Signaling as well as in ABA Signaling  526
20.2.3  SnRK2–AREB/ABF Pathway Plays a Central Role in ABA-Mediated Gene Expression in Response to Cellular Dehydration  528
20.2.4  AREB/ABFs are Master Transcription Factors that Regulate ABA-Mediated ABRE-Dependent Gene Expression in Response to Dehydration Stress  529
20.2.5  ABRE Functions as a Major cis-Acting Element in ABA-Responsive Gene Expression  530
20.3  ABA-Mediated Gene Expression in Seed Dormancy  532
20.3.1  ABA has an Important Role in the Control of Seed Dormancy  532
20.3.2  SnRK2s are Central Regulators in ABA Signaling for Seed Dormancy  534
20.3.3  Quantitative Trait Locus Analyses Provide Novel Factors for the Control of Seed Dormancy  535
20.4  Role of ABA in Plant Adaptation to Land and Environmental Changes  536
20.5  Potential Application of ABA Signaling Components to Improve Crop Productivity Under Climate Change  537
20.6  Future Perspectives  538
References  541

21  Regulatory Role of Transcription Factors in Abiotic Stress Responses in Plants  555
Dumbala Srinivas Reddy, Pooja Bhatnagar Mathur, and K.K.Sharma
21.1  Introduction  555
21.2  bZIP Proteins  557
21.3  MYB-Like Proteins  557
21.4  MYC-Like bHLH Proteins  558
21.4.1  Cooperation of MYC and MYB Proteins  560
21.5  HD-ZIP Proteins  561
21.6  AP2/EREBP Domain Proteins  562
21.7  DREB Subfamily  562
21.8  CBF/DREB Genes from Arabidopsis  564
21.9  CBF/DREB Regulation in Arabidopsis  565
21.9.1  Promoter Regions of the CBF/DREB Genes of Arabidopsis  565
21.9.2 Expression of CBFs is Modulated by Temperature 565
21.9.3 Regulation of the CBF Pathway in Arabidopsis 566
21.9.3.1 Upstream Regulators of the CBF Pathway 567
21.9.3.2 Downstream Regulators of the CBF Pathway 569
21.9.4 CBF3 Integrates the Activation of Multiple Components of the Cold Response 569
21.9.4.1 ESK1 570
21.9.5 Parallel Pathway to CBFs 570
21.9.5.1 RAV1 and ZAT12 May Follow Parallel Pathways to CBFs 571
21.10 DREB1A-Targeted Genes 571
21.11 Overexpression of DREB Genes in Plant Species 572
21.11.1 Overexpression of DREB Genes in Transgenic Arabidopsis 572
21.11.2 Heterologous Expression of Arabidopsis DREB Genes in Transgenic Plants 573
21.11.3 DREB Genes Have Discrepant Expression in Monocots and Dicots 576
21.11.4 CBF/DREB1 Genes of Arabidopsis and Rice are Functionally Different 576
21.12 Conclusion 577
References 577

22 Transcription Factors: Modulating Plant Adaption in the Scenario of Changing Climate 589
Swati Puranik and Manoj Prasad
22.1 Catastrophes of the Changing Climate 589
22.2 Molecular Reprogramming Events Mitigate Environmental Constraints 590
22.3 Classification of Transcription Factors 592
22.3.1 AREB/ABF Proteins 593
22.3.2 MYC/MYB Transcription Factors 593
22.3.3 CBF/DREB Transcription Factors 594
22.3.4 NAC and ZF-HD Proteins 595
22.3.5 WRKY Transcription Factors 596
22.3.6 ZF Proteins 596
22.4 Conclusion and Future Perspectives 597
References 597

23 Role of Transcription Factors in Abiotic Stress Tolerance in Crop Plants 605
Neelam R. Yadav, Jyoti Taunk, Asha Rani, Bharti Aneja, and Ram C. Yadav
23.1 Introduction 606
23.2 AP2/ERF Regulon 607
23.3 CBF/DREB Regulon 609
23.4 NAC Regulon 611
23.5 ZF-HD Regulon 614
23.6 MYB/MYC Regulon 615
23.6.1 MYBs and Cold Stress 618
23.6.2 MYBs and Salinity Tolerance 619
23.7 AREB/ABF Regulon 621
23.8 Transcription Factor WRKY 624
23.9 Conclusions 626
References 627

24 Coping with Drought and Salinity Stresses: Role of Transcription Factors in Crop Improvement 641
Karina F. Ribichich, Agustín L. Arce, and Raquel Lía Chan
24.1 Transcription Factors: A Historical Perspective 641
24.2 Plant Transcription Factor Families Implicated in Drought and Salinity 644
24.2.1 MYB Family 645
24.2.2 bHLH Family 649
24.2.3 bZIP Family 649
24.2.4 NAC Family 650
24.2.5 AP2/ERF Family 651
24.2.6 WRKY Family 652
24.2.7 HD Family 653
24.3 Crop Domestication: Examples of the Major Role of Transcription Factors 654
24.3.1 Maize Domestication: Increasing Apical Dominance 654
24.3.2 Rice Domestication: Reducing Grain Shattering 655
24.3.3 Barley Domestication: Yield to the Yield 656
24.4 Drought and Salinity: From Perception to Gene Expression 657
24.4.1 Early Signaling Events 658
24.4.2 ABA-Dependent Pathway 659
24.4.3 ABA-Independent Pathway 662
24.5 Transcription Factor Gene Discovery in Stress Responses 663
24.6 The Long and Winding Road to Crop Improvement 665
References 672

25 Role of Na\(^+\)/H\(^+\) Antiporters in Na\(^+\) Homeostasis in Halophytic Plants 685
Pradeep K. Agarwal, Narendra Singh Yadav, and Bhavanath Jha
25.1 Introduction 685
25.2 Tissue-Specific Adaptation of Halophytes 687
25.2.1 Succulence 687
25.2.2 Salt Secretion by Salt Glands 688
25.2.3 Salt Secretion by Bladder Cells 688
25.2.4 Salt-Secreting Hairs 689
25.2.5 Salt Exclusion by Ultrafiltration at the Membranes of Root Cells 689
25.2.6 Salt-Saturated Organs 689
25.3 Ion Transporters 690
25.3.1 Plasma Membrane Transporters 690
25.3.1.1 SOS1 690
25.3.1.2 Plasma Membrane H\(^+\)-ATPase 692
25.3.2 Vacuolar Transporters 692
25.3.2.1 NHX1 692
25.3.2.2 Vacuolar H\(^+\)-ATPase 694
25.3.2.3 H\(^+\)-PPase (V-PPase) 695
25.4 Conclusion and Perspectives 697
References 698

26 Role of Plant Metabolites in Abiotic Stress Tolerance Under Changing Climatic Conditions with Special Reference to Secondary Compounds 705

Akula Ramakrishna and G.A. Ravishankar

26.1 Introduction: Plant Secondary Metabolites 705
26.2 Climate Change 706
26.3 Role of Secondary Metabolites Under Changing Climatic Conditions 706
26.3.1 Carotenoids 707
26.3.2 Polyamines 708
26.3.3 Carbohydrates 708
26.3.4 Antioxidants 708
26.3.5 Phenolic Compounds 709
26.3.6 Stress Proteins 710
26.3.7 Antifreeze Proteins 710
26.3.8 Heat Shock Proteins 710
26.3.9 Dehydrins 710
26.4 Role of Signaling Molecules During Abiotic Stress 711
26.4.1 Nitric Oxide 711
26.4.2 Jasmonates 711
26.4.3 Brassinosteroids 712
26.4.4 Salicylic Acid 712
26.4.5 Phytohormones 712
26.5 Role of Secondary Metabolites in Drought, Salt, Temperature, Cold, and Chilling Stress 713
26.5.1 Drought Stress 713
26.5.2 Salt Stress 713
26.5.3 Temperature Stress 714
26.5.4 Cold Stress 715
26.5.5 Chilling Stress 715
26.6 Conclusion 716
References 716
27 Metabolome Analyses for Understanding Abiotic Stress Responses in Plants to Evolve Management Strategies 727

Usha Chakraborty, Bhumika Pradhan, and Rohini Lama

27.1 Introduction 728

27.2 Metabolite Changes During Abiotic Stresses 729

27.2.1 Proline and Glycine Betaine 729

27.2.2 Carbohydrates 733

27.2.3 Polyamines 735

27.3 Stress Hormones 736

27.3.1 ABA 737

27.3.2 Salicylic Acid 738

27.3.3 Jasmonic Acid and Ethylene 738

27.4 Antioxidants 739

27.5 Stress Proteins and Protein Kinases 740

27.6 Stress-Responsive Gene Expression 741

27.7 Role of MicroRNAs in Abiotic Stress 742

27.8 Conclusion 743

References 744

28 Metabolomic Approaches for Improving Crops Under Adverse Conditions 755

Prabodh Kumar Trivedi, Nehal Akhtar, Parul Gupta, and Pravendra Nath

28.1 Introduction 755

28.2 Different Approaches to Study Metabolomics 756

28.3 Plant Metabolome Alterations During Adverse Conditions 757

28.3.1 Light 758

28.3.2 Temperature 760

28.3.2.1 High Temperature 760

28.3.2.2 Cold Stress 761

28.3.3 Drought 763

28.3.4 Salinity 766

28.3.5 Hypoxia 767

28.3.6 Heavy Metals 768

28.4 Genetic Engineering for Metabolite Modulation for Stress Tolerance 770

References 774

29 Improvement of Cereal Crops through Androgenesis and Transgenic Approaches for Abiotic Stress Tolerance to Mitigate the Challenges of Climate Change in Sustainable Agriculture 785

S.M. Shahinul Islam, Israt Ara, and Narendra Tuteja

29.1 Background 786

29.2 Androgenesis for Crop Improvement 787

29.2.1 Major Factors Influencing Androgenesis 788
29.2.1.1 Genotype and Other Physical Conditions of the Donor Plant 788
29.2.1.2 Anther Wall 789
29.2.1.3 Culture Medium 789
29.2.1.4 Stage of Microspore or Pollen Development 789
29.2.1.5 Pretreatment and Stress Factors 789
29.2.1.6 Confirmation of Ploidy Status 789
29.2.2 Problems Associated with Albinisms in Androgenesis 790
29.2.3 Genetic Transformation and in Combination with Androgenesis 790
29.2.4 Development of Major Abiotic Stress-Tolerant Crops by Androgenesis, Transformation, and the Combination of Both Methods 791
29.2.4.1 Salinity 792
29.2.4.2 Drought 801
29.2.4.3 Heavy Metals 801
29.2.4.4 Extreme Temperature (Cold/Heat) 802
29.2.4.5 Flood/Water Logging 802
29.2.4.6 Herbicide Resistance 803
29.2.4.7 Osmotic and Oxidative Stress 803
29.3 Concluding Remarks 804
References 805

30 Bioprospection of Weed Species for Abiotic Stress Tolerance in Crop Plants Under a Climate Change Scenario: Finding the Gold Buried within Weed Species 815
Meenal Rathore, Raghwendra Singh, and Bhumesh Kumar
30.1 Introduction 815
30.2 Climate Change and Agriculture 816
30.2.1 Average Surface Temperature 817
30.2.2 Change in Rainfall Amount and Pattern 817
30.2.3 Atmospheric CO₂ Level 818
30.2.4 Tropospheric Ozone 818
30.2.5 Drought 818
30.2.6 UV-B Radiation 819
30.3 Weeds as a Source of Genetic Materials for Abiotic Stress Tolerance 820
30.3.1 Thermotolerance 821
30.3.2 Drought Tolerance 823
30.3.3 Salinity Tolerance 824
30.3.4 Excess Water (Flooding) Tolerance 826
30.3.5 Tolerance to UV-B Radiation 828
30.3.6 Tolerance to Ozone 829
30.4 Conclusion 830
References 830
Part Four  Crop Improvement Under Climate Change  837

31  Climate Change and Heat Stress Tolerance in Chickpea  839

31.1 Introduction  840
31.2 Effect of Heat Stress on Chickpea  842
31.3 Screening Techniques for Heat Tolerance  844
31.4 Physiological Mechanisms Underlying Heat Tolerance  846
31.5 Genetic Variability for Heat Tolerance  847
31.6 Breeding Strategies for Heat Tolerance  848
References  850

32  Micropropagation of Aloe vera for Improvement and Enhanced Productivity  857

32.1 Introduction  858
32.1.1 Human-Induced Climate Changes and Constraints on Ecosystem Services  859
32.2 Aloe as a Plant Resource of Dry Habitats  860
32.3 Aloe Biology  863
32.4 Genetic Resources and Biodiversity of Aloe  864
32.5 Biotechnology for Characterization, Conservation, Improvement, and Productivity Enhancement of Aloe  865
32.6 Cloning and Mass Propagation of Aloe Through Tissue Culture  866
32.7 Cloning of A. vera (Ghee-Kanwar/Gwar-Patha)  868
32.7.1 Materials and Methods  868
32.7.1.1 Establishment of Cultures and Multiplication of Clonal Shoots  868
32.7.1.2 Rooting of In Vitro Produced Shoots  871
32.7.1.3 Hardening and Acclimatization of the Cloned Plantlets of A. vera  871
32.7.2 Results  872
32.8 Conclusions  873
References  874

33  Climate Change and Organic Carbon Storage in Bangladesh Forests  881
Mohammed Alamgir and Stephen M. Turton

33.1 Introduction  882
33.2 Forests in Bangladesh: A General Overview  883
33.2.1 Mangrove Forests  884
33.2.2 Hill Forests  886
33.2.3 Village Forests 886
33.2.4 Plain Land Sal Forests 887
33.3 Climate Change Scenarios in Bangladesh 887
33.4 Trends of Organic Carbon Storage in Different Forest Types 889
33.5 Abiotic Stress Tolerance of Trees of Different Forest Types 892
33.6 Likely Impacts of Climate Change on Organic Carbon Storage in Forests 894
33.7 Question of Sustainability of Organic Carbon Storage 896
33.8 Conclusion 899

References 899

34 Divergent Strategies to Cope with Climate Change in Himalayan Plants 903

Sanjay Kumar

34.1 Why Himalaya? 903
34.2 Climate Change is Occurring in Himalaya 907
34.3 Plant Response to Climate Change Parameters in Himalayan Flora 908
34.3.1 How to Enhance Efficiency of Carbon Uptake? Plants at High Altitude Offer Clues 910
34.3.2 Managing Oxidative Stress Nature’s Way 911
34.3.2.1 Engineering SOD for Climate Change 913
34.3.3 Transcriptome Analysis Offers Genes and Gene Suits for Tolerance to Environmental Cues 914
34.3.3.1 Clues from Plants at High Altitude 914
34.3.3.2 Clues from Plants at Low Altitude 916
34.3.3.3 Summing Up the Information from Transcriptome Analysis 919
34.4 Impact on Secondary Metabolism Under the Climate Change Scenario 919
34.5 Path Forward 924

References 926

35 In Vitro Culture of Plants from Arid Environments 933

Harchand R. Dagla, Shari Nair, Deepak K. Vyas, and Juleri M. Upendra

35.1 Introduction 933
35.2 Materials and Methods: Establishment of In Vitro Cultures 936
35.2.1 Mature Explants 936
35.2.2 Juvenile Explants 936
35.3 Results and Discussion 936

References 938

36 Salicylic Acid: A Novel Plant Growth Regulator – Role in Physiological Processes and Abiotic Stresses Under Changing Environments 939

Pushp Sharma

36.1 Introduction 940
36.2 Metabolic and Biosynthetic Pathways 940
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>36.3 Signaling and Transport</td>
<td>941</td>
</tr>
<tr>
<td>36.4 Salicylic Acid-Regulated Physiological Processes</td>
<td>942</td>
</tr>
<tr>
<td>36.4.1 Seed Germination</td>
<td>943</td>
</tr>
<tr>
<td>36.4.2 Seed Germination Under Abiotic Stress</td>
<td>943</td>
</tr>
<tr>
<td>36.4.3 Salicylic Acid Cross-Talk with ABA and Gibberellins During</td>
<td>944</td>
</tr>
<tr>
<td>Germination</td>
<td></td>
</tr>
<tr>
<td>36.4.4 Ubiquitin–Proteosome System</td>
<td>944</td>
</tr>
<tr>
<td>36.5 Growth and Productivity</td>
<td>945</td>
</tr>
<tr>
<td>36.5.1 Vegetative Growth</td>
<td>946</td>
</tr>
<tr>
<td>36.5.2 Salicylic Acid Signaling and Growth Rate</td>
<td>947</td>
</tr>
<tr>
<td>36.5.3 NPR1: Regulation of Cell Growth and Death</td>
<td>948</td>
</tr>
<tr>
<td>36.5.4 Metabolic Networks Between Salicylic Acid and Auxin Signaling</td>
<td>948</td>
</tr>
<tr>
<td>During Vegetative Growth</td>
<td></td>
</tr>
<tr>
<td>36.5.5 Plant Growth Regulation: Role of Salicylic Acid, ROS, and the</td>
<td>949</td>
</tr>
<tr>
<td>Mitogen-Activated Protein Kinase Pathway</td>
<td></td>
</tr>
<tr>
<td>36.6 Flowering</td>
<td>950</td>
</tr>
<tr>
<td>36.6.1 Interaction with Photoperiod and Autonomous Pathways</td>
<td>951</td>
</tr>
<tr>
<td>36.7 Photosynthesis and Plant–Water Relations</td>
<td>952</td>
</tr>
<tr>
<td>36.7.1 Salicylic Acid and Pigments</td>
<td>952</td>
</tr>
<tr>
<td>36.7.2 Photosynthesis and Related Traits</td>
<td>953</td>
</tr>
<tr>
<td>36.7.3 Light Acclimation and Redox Homeostasis</td>
<td>953</td>
</tr>
<tr>
<td>36.7.4 Role in Stomatal Closure</td>
<td>954</td>
</tr>
<tr>
<td>36.7.5 Leaf, Chloroplast Structure, and RuBisCO Activity</td>
<td>955</td>
</tr>
<tr>
<td>36.8 Respiration: Salicylic Acid Regulation of the Alternative</td>
<td>956</td>
</tr>
<tr>
<td>Oxidase Pathway</td>
<td></td>
</tr>
<tr>
<td>36.9 Nitrogen Fixation</td>
<td>957</td>
</tr>
<tr>
<td>36.9.1 Rhizobium–Legume Symbiosis</td>
<td>958</td>
</tr>
<tr>
<td>36.10 Salicylic Acid Regulates Antioxidant Systems</td>
<td>959</td>
</tr>
<tr>
<td>36.11 Senescence</td>
<td>960</td>
</tr>
<tr>
<td>36.11.1 Salicylic Acid Regulation of Senescence-Associated Genes</td>
<td>960</td>
</tr>
<tr>
<td>36.11.2 WRKY53 in the Integration of Salicylic Acid and Jasmonic Acid</td>
<td>960</td>
</tr>
<tr>
<td>Signaling for Senescence Regulation</td>
<td></td>
</tr>
<tr>
<td>36.11.3 Conservation of the Salicylic Acid Signaling Pathway in the</td>
<td>961</td>
</tr>
<tr>
<td>Senescence Process of Different Tissues</td>
<td></td>
</tr>
<tr>
<td>36.11.4 Autophagy During Leaf Senescence</td>
<td>961</td>
</tr>
<tr>
<td>36.12 Salicylic Acid and Stress Mitigation</td>
<td>963</td>
</tr>
<tr>
<td>36.12.1 Biotic Stress</td>
<td>963</td>
</tr>
<tr>
<td>36.12.2 Abiotic Stresses</td>
<td>965</td>
</tr>
<tr>
<td>36.12.2.1 Heavy Metal Stress</td>
<td>965</td>
</tr>
<tr>
<td>36.12.2.2 Salinity Stress</td>
<td>966</td>
</tr>
<tr>
<td>36.12.2.3 Temperature Stress</td>
<td>967</td>
</tr>
<tr>
<td>36.12.2.4 UV Radiation or Ozone Stress</td>
<td>969</td>
</tr>
<tr>
<td>36.12.2.5 Water Stress</td>
<td>970</td>
</tr>
<tr>
<td>36.12.3 Salicylic Acid and Macrophyta Adaptation</td>
<td>971</td>
</tr>
<tr>
<td>36.13 Conclusion and Future Strategies</td>
<td>971</td>
</tr>
<tr>
<td>References</td>
<td>972</td>
</tr>
</tbody>
</table>
37 Phosphorus Starvation Response in Plants and Opportunities for Crop Improvement 991
Bipin K. Pandey, Poonam Mehra, and Jitender Giri

37.1 Introduction 991
37.2 Phosphate Acquisition from Soil Solution 992
37.3 Sensing of Pi Status in Plants 993
37.4 Local and Systemic Response in Pi Deficiency 995
37.4.1 Local Pi Responses 995
37.4.1.1 Effect on Primary Root Growth 995
37.4.1.2 Root Hair Proliferation 997
37.4.1.3 Formation of Lateral Roots 999
37.4.2 Systemic Pi Response 999
37.4.2.1 Genetic Network Regulating Systemic Response in Pi Starvation 1000
37.4.2.2 Sugars are Essential for the Pi-Deficiency Response 1001
37.5 Phytohormones Mediate both Local and Systemic Response in Pi Deficiency 1001
37.5.1 Role of Auxin in Pi Deficiency 1001
37.5.2 Cytokinin and Pi Deficiency 1002
37.5.3 Ethylene and Pi Deficiency 1002
37.5.4 Gibberellic Acid and Pi Deficiency 1003
37.6 Strategies for Improving Pi-Acquisition Efficiency and Pi-Use Efficiency in Crop Plants 1003
37.7 Conclusions and Future Prospects 1007
References 1008

38 Bacterial Endophytes and their Significance in the Sustainable Production of Food in Non-Legumes 1013
Aparna Raturi, Prasad Gyaneshwar, Sunil K. Singh, Nisha Tak, and Hukam S. Gehlot

38.1 Introduction 1014
38.2 Soil, Microbes, and Plants (Rhizosphere/Rhizodeposition) 1015
38.3 Bacterial Endophytes 1016
38.3.1 Bacterial Endophytes Help Plants to Defend Against Biotic and Abiotic Stress 1018
38.3.2 Mechanism of Action of Endophytes 1018
38.4 Nitrogen Fixation by Free-Living versus Endophytic Bacteria 1019
38.5 Diazotrophic Bacterial Endophytes 1020
38.6 Non-Legumes (Cereals and Grasses) and Diazotrophic Bacterial Endophytes 1022
38.6.1 Sugarcane (Saccharum officinalis) 1022
38.6.2 Rice (Oryza sativa) 1022
38.6.3 Maize/Sorghum 1023
38.6.4 Pennisetum glaucum 1023
38.6.5 Grasses 1024
38.6.6 Other Plants 1024
38.7 Bacterial Endophytes and Stress Tolerance 1025
## Contents

38.8  Natural Products from Endophytic Bacteria  1025  
38.9  Antagonistic and Synergistic Interactions  1027  
38.10  Role in Phytoremediation  1028  
38.11  Genomics of Bacterial Endophytes  1029  
38.12  Metagenomics of Rhizospheric Microbes to Study Molecular and Functional Diversity  1029  
38.13  Concluding Remarks  1031  
References  1032  

### 39  Endophytic Fungi for Stress Tolerance  1041  
* Nutan Kaushik and Vikram Kumar  
39.1  What are Endophytes?  1041  
39.2  Endophytic Fungi and Stress Tolerance  1042  
39.2.1  Drought Stress  1043  
39.2.2  Temperature Stress  1043  
39.2.3  Salt Stress  1045  
39.2.4  Heavy Metal Stress  1046  
39.3  Stress Tolerance Mechanisms  1046  
39.3.1  Osmotic Adjustment  1047  
39.3.2  Water-Use Efficiency  1048  
39.3.3  Reactive Oxygen Species (ROS)  1048  
39.3.4  Antioxidant Enzymes  1049  
39.4  Conclusion  1049  
References  1050  

### 40  Polyamines and their Role in Plant Osmotic Stress Tolerance  1053  
* Kamala Gupta, Abhijit Dey, and Bhaskar Gupta  
40.1  Introduction  1053  
40.2  Polyamine Metabolism in Plants  1055  
40.3  Polyamines and Osmotic Stress Response  1056  
40.3.1  Plant Response to Hypo- and Hyperosmotic Stress Tolerance  1056  
40.3.2  Role of Exogenously Applied Polyamines to Alleviate Osmotic Stress in Plants  1058  
40.3.3  Transgenics in Plant Polyamines Research Related to Osmotic Stress  1061  
40.3.4  Polyamine-Mediated Plant Osmotic Stress Signal Transduction: Molecular Aspects and Cross-Talk  1062  
40.4  Conclusion  1065  
References  1065  

Index  1073