PHYSIOLOGY OF SALT STRESS IN PLANTS

PERCEPTION, SIGNALLING, OMICS AND TOLERANCE MECHANISM

Edited By

Pratibha Singh | Madhulika Singh Rajiv Kumar Singh | Sheo Mohan Prasad



สำนักหอสมุด มหาวิทยาลัยเชียงใหม่

·616589683 `012939600 `12939600

Physiology of Salt Stress in Plants

Perception, Signalling, Omics and Tolerance Mechanism

Edited by

Pratibha Singh

Ranjan Plant Physiology and Biochemistry Laboratory, Department of Botany University of Allahabad Prayagraj, Uttar Pradesh, India

Madhulika Singh

Centre of Advanced Studies in Botany Banaras Hindu University Varanasi, Uttar Pradesh, India



Rajiv Kumar Singh

Horticultural Scientist Krishi Vigyan Kendra, Sohaon Ballia, Uttar Pradesh, India

Sheo Mohan Prasad

Ranjan Plant Physiology and Biochemistry Laboratory, Department of Botany University of Allahabad Prayagraj, Uttar Pradesh, India



Contents

List of Contributors xii Preface xvi

1 An Introduction to Salt Stress Perception and Toxicity Level: Worldwide Report at a Glance 1 v

Atun Roy Choudhury, Neha Singh, Ayushi Gupta, and Sankar Ganesh Palani

- 1.1 Soil Salinity: An Introduction 1
- 1.2 Salt Stress Perception and Current Scenario 2
- 1.3 Types of Salt Stress 3
- 1.4 Origin of Problems 4
- 1.5 Salt Toxicity Level: A Worldwide Report 4
- 1.6 Effect of Salt Stress on Flora and Fauna of the Ecosystem 7
- 1.7 Role in Sustainable Agriculture 8
- 1.8 Unintended Effects of Salt-Containing Substance Application in Agricultural Land 9
- 1.9 Role of Salt Toxicity in the Operation of Green Revolution 10
- 1.10 Reaching the Current Status and Conclusion 11 Acknowledgments 12 References 12

- Vivekanand Tiwari, Abhay Kumar, and Pratibha Singh
- 2.1 Soil Salinity and Plants 16
- 2.2 Crop Loss Due to Salt Toxicity An Estimation Worldwide 17
- 2.3 Effect of Salt Stress on Target and Nontarget Plants and Microorganisms 18
- 2.4 Effect of Salt Stress on Physiology of Crop Plants 20
- 2.4.1 Effect of Salt Stress on Chlorophyll Biosynthesis, Chloroplast Functioning, and Photophosphorylation 21
- 2.4.1.1 Chlorophyll Biosynthesis in Salt Stress 21
- 2.4.1.2 Salt Stress Affects Chloroplast Function 22
- 2.4.1.3 Photophosphorylation in Salt Stress 23
- 2.4.2 Glycolysis, Kreb'sCycle Enzymes, Oxidative Phosphorylation, and Other Mitochondrial Functioning 23
- 2.4.2.1 Glycolytic Pathway in Salt Stress 24

² Effects of Salt Stress on Physiology of Crop Plants: At Cellular Level 16

- vi Contents
 - 2.4.2.2 TCA Cycle in Salt Stress 24
 - 2.4.2.3 Salt Stress and Oxidative Phosphorylation 25
 - 2.4.3 Peroxisome Functioning 25
 - 2.5 Halophytes and Their Physiology 26
 - 2.5.1 Ion Homeostasis in a Halophyte 27
 - 2.5.2 Osmotic Adjustment 28
 - 2.5.3 Physiological and Metabolic Adaptation of Halophytes 28
 - 2.6 Halophytes in Agriculture and Land Management 29
 - 2.7 Conclusion and Future Perspectives 31 References 32

3 Effects of Salt Stress on Biochemistry of Crop Plants 38

Poonam Yadav and Durgesh Kumar Jaiswal

- 3.1 Introduction 38
- 3.2 Effects of Salt Stress on Lipid Metabolism 40
- 3.3 Effects of Salt Stress on the Amino Acids Synthesis and Nitrogen Metabolism 41
- 3.4 Effects of Salt Stress on Protein Biosynthesis 43
- 3.5 Effect of Salt Stress on the Oxidation of Membrane Proteins 43
- 3.6 Effect of ROS on the Nucleic Acid Formation 44
- 3.7 DNA-Protein Cross-links 44
- 3.7.1 Type 1 DPC 45
- 3.7.2 Type 2 DPC 45
- 3.7.3 Type 3 & 4 DPC 45
- 3.8 Effect of Salt Stress on Dephosphorylation of RNA and DNA 46
- 3.9 Future Advances and Conclusion 46 References 47
- 4 Salt Ion Transporters in Crop Plants at Cellular Level 53
 - Ria Khare, Gurpreet Sandhu, Aruba Khan, and Prateek Jain
- 4.1 Introduction 53
- 4.2 Absorption of Na⁺ from Soil and Its Compartmentalization in Plant Cell 54
- 4.3 Salt Ions Regulation in Plant Cells and Tissues 56
- 4.4 Role of Ion Channels and Salt Ion Transporter in Crop Plants at Cellular Level 57
- 4.5 Transport of Na⁺ Through SOS Signal Transduction Pathway: At Cellular Level 61
- 4.6 Role of Salt Tolerance Responsive Genes in Transport of Na⁺ and Cl⁻ Ions 62
- 4.7 Role of Ions in Salt Stress Tolerance 63
- 4.8 Reaching the Current Status and Conclusion 65 References 65
- **5** Salt Ion and Nutrient Interactions in Crop Plants: Prospective Signaling 74 *Ria Khare and Prateek Jain*
- 5.1 Introduction 74

- 5.2 Effects of Salt Stress on Nutrient Absorption 75
- 5.3 Effects of Salt Stress on Nutrient Cycling in Crop Plants 76
- 5.4 Salt Ion and Nutrient Interactions in Crop Plants 77
- 5.5 Effect of Salt Stress on Nutrient Transporters 78
- 5.5.1 K Transporters 78
- 5.5.2 N Transporters 79
- 5.5.3 P Transporters 80
- 5.5.4 S Transporters 80
- 5.6 Role of Nutrient Interactions: Prospective Signaling 81
- 5.7 Future Prospective and Conclusion *81* References *82*
- 6 Effects of Salt Stress on the Morphology, Anatomy, and Gene Expression of Crop Plants 87

Pragati Kumari, Arvind Gupta, Harish Chandra, Pratibha Singh, and Saurabh Yadav

- 6.1 Introduction 87
- 6.2 Salt Stress and Effects on Morphology of Plants 89
- 6.3 Photosynthetic Pigments and Osmolytes Accumulation 91
- 6.4 Effect of Saline Stress on Floral Organs 91
- 6.5 Anatomical Features and Salt Stress 92
- 6.5.1 Relationship of Structure–Function Operation in Roots 93
- 6.5.2 Transport Through Xylem 94
- 6.5.3 Transport into the Phloem 94
- 6.6 Yield and Related Traits 95
- 6.7 Salt Stress and its Effect on Gene Expression 96
- 6.8 Conclusion 98 References 98

7 Effect of Salt Stress on Soil Chemistry and Plant-Atmosphere Continuum (SPAC) 106

Gunjan Goyal, Aruna Yadav, and Gunjan Dubey

- 7.1 Introduction 106
- 7.1.1 Soil Salinization Types and Causes 107
- 7.2 Effect of Salt Stress on Soil Component 107
- 7.2.1 Effect of Salt Stress on Abiotic Component of Soil and Soil Health 108
- 7.2.2 Effect of Salt Stress on Biotic Component of Soil and Soil Health 109
- 7.3 Soil Chemistry Affecting Factors in Agricultural Land 110
- 7.4 Soil Salinity Effect on Crop Plants 110
- 7.4.1 Germination 110
- 7.4.2 Growth 111
- 7.4.3 Photosynthesis and Photosynthetic Pigments 113
- 7.4.4 Mineral Uptake and Assimilation 114
- 7.4.5 Oxidative Stress 115

7.4.6 Yield 115

7.5 An Introduction to Soil, Plant-Atmosphere Continuum (SPAC) 115

- viii Contents
 - Salt Absorption by Root Tissues and Their Effect on Plant-Atmosphere 7.6 Continuum 116
 - 7.7 Translocation of Salt Ions in the Vascular System of Crop Plants 118
 - Mechanism of Sodium Influx Into Cytosol 119 7.7.1
 - Mechanism of Na⁺ Compartmentalization in Vacuoles 119 7.7.2
 - The SOS Pathway 120 7.7.3
 - 7.7.4 Effect of Salt Stress on Xvlem Transport 121
 - Effect of Salt Stress on Phloem Loading 122 775
 - 7.8 Current Status and Conclusion 122 Acknowledgements 122 References 123

8 Effects of Salt Stress on Nutrient Cycle and Uptake of Crop Plants 129

Lav Kumar Jaiswal, Prabhakar Singh, Rakesh Kumar Singh, Tanamyee Nayak, Yashoda Nandan Tripathi, Ram Sanmukh Upadhyay, and Ankush Gupta

- Introduction 129 8.1
- 8.2 Limitation of Nutrient Cycle and Uptake of Nutrients 131
- 8.2.1 Phosphorus Limitation 132
- 8.2.2 Nitrogen Limitation 132
- 8.3 Nutrient Cycle or Biogeochemical Cycle 133
- 8.3.1 Water Cycle or Hydrological Cycle 133
- 8.3.2 Carbon Cycle 134
- 8.3.3 Nitrogen Cycle 134
- 8.3.4 Oxygen Cycle 136
- 8.3.5 Phosphorus Cycle 137
- 8.3.6 Sulfur Cycle 139

9.1

- 8.3.7 Calcium Cycle 140
- Effect of Salt Stress on Carbon Cycle 141 8.4
- Effect of Salt Stress on Oxygen and Water Cycle 142 8.5
- 8.5.1 Effect of Salt Stress on Oxygen Cycle 142
- 8.5.2 Effect of Salt Stress on Water Cycle 142
- Effect of Salt Stress on Nitrogen Fixing Bacteria and Biogeochemical Cycle 8.6 of Nitrogen 143
- 8.7 Effect of Salt Stress on Phosphorous Bacteria and Biogeochemical Cycle of Phosphorus 144
- Effect of Salt Stress on Sulfur Bacteria and Biogeochemical Cycle of Sulfur 145 8.8
- 8.9 Future Prospective and Conclusion 146 References 147
- 9 Salt-Induced Effects on Crop Plants and Counteract Mitigating Strategy by Antioxidants System 154

Indrajeet Kumar, Umesh Kumar, Prince Kumar Singh, and Rajesh Kumar Sharma Introduction 154

- 9.2 Formation of Salt-Induced Indirect Products (Oxidative Biomarkers) in Crops 155
- 9.3 Effect of Salt Stress on Crop Plants 156
- 9.4 Consequences Effect of Oxidative Biomarkers in Crop Plants 158
- 9.4.1 Lipid Peroxidation 158
- 9.4.2 Effect on Proteins 160
- 9.4.3 Effects on Carbohydrates 160
- 9.4.4 Effect on Polynucleic Acids 161
- 9.5 Generation of Self-defense Mitigating Strategy in Crop Plants 162
- 9.5.1 Counteract Mitigating Strategy by Enzymatic Antioxidants System 162
- 9.5.1.1 Superoxide Dismutase (SOD) 163
- 9.5.1.2 Catalase (CAT) 163
- 9.5.1.3 Ascorbate-Glutathione (AsA-GSH) Cycle Enzymes 163
- 9.5.1.4 Ascorbate Peroxidases (APX) 163
- 9.5.1.5 Monodehydroascorbate Reductase (MDHAR) and Dehydroascorbate Reductase (DHAR) *164*
- 9.5.1.6 Glutathione Reductase (GR) 164
- 9.5.1.7 Guaiacol Peroxidase (GPX) 164
- 9.5.2 Counteract Mitigating Strategy by Nonenzymatic Antioxidants System 165
- 9.6 Conclusion and Future Prospective 168 References 169
- 10 Effects of Salt Stress on Osmolyte Metabolism of Crop Plants and Mitigating Strategy by Osmolyte 177

Abreeq Fatima, Garima Singh, Anuradha Patel, Sanjesh Tiwari, Divya Gupta, Anurag Dubey, Dilip Kumar Prajapati, and Sheo Mohan Prasad

- 10.1 Introduction 177
- 10.2 Groups and Biosynthetic Pathways of Osmolytes in Crop Plant 178
- 10.2.1 Polyamines and Their Biosynthetic Pathways in the Cell Organelles of Crop Plant 178
- 10.2.2 Betaine and Their Biosynthetic Pathways in the Cell Organelles of Crop Plant *179*
- 10.2.3 The Biosynthetic Pathway of Carbohydrate Sugar, Sugar Alcohol, and Amino Acids in the Cell Organelles of Crop Plant 181
- 10.3 Effect of Salt Stress on Osmolyte Production and Work Action 183
- 10.4 The Osmotic and Ionic Adjustment Under Salt Stress Tolerance Mechanism 186
- 10.5 Conclusion 188
 - References 189
- 11Salt Stress Toxicity Amelioration by Phytohormones, Synthetic Product,
and Nutrient Amendment Practices198

Divya Gupta, Garima Singh, Sanjesh Tiwari, Anuradha Patel, Abreeq Fatima, Anurag Dubey, Neha Naaz, Jitendra Pandey, and Sheo Mohan Prasad x Contents

- 11.1 Introduction 198
- 11.2 Structure and Mechanism of Action of Phytohormones Under Salt Stress 200
- 11.3 Structural, Physiological, and Biochemical Nature of Phytohormones Under Salt Stress 201
- 11.3.1 Abscisic Acid (ABA) 201
- 11.3.2 Cytokinins (CKs) 202
- 11.3.3 Gibberellins (GAs) 202
- 11.3.4 Auxins (AUXs) 203
- 11.3.5 Brassinosteroids (BRs) 203
- 11.3.6 Salicylic Acid (SA) 203
- 11.3.7 Jasmonic Acid (JA) 204
- 11.4 Salt Stress Toxicity Amelioration by Exogenous/Endogenous Phytohormones 204
- 11.4.1 Auxin 208
- 11.4.2 Gibberellins 208
- 11.4.3 Cytokinin 209
- 11.4.4 Brassinosteroids 209
- 11.4.5 Salicylic Acid 210
- 11.5 Salt Toxicity Amelioration by Exogenous Synthetic Products 210
- 11.6 Salt Toxicity Amelioration by Exogenous Nutrient Amendment Practices 213
- 11.7 Future Prospective and Conclusion 215 References 216
- **12 Crop Plants Develop Extracellular Signaling Products Against Salt Stress** *229 Santwana Tiwari, Nidhi Verma, Shikha Singh, Shivam Gupta, Madhulika Singh,*
 - Pratibha Singh, Jitendra Pandey, and Sheo Mohan Prasad
- 12.1 Introduction 229
- 12.2 Site of Synthesis of Extracellular Signaling Products 233
- 12.3 Release of Extracellular Products by Cells of Cyanobacteria, Algae, and Crop Plants Under Salt Stress: Antioxidants, Enzymes, and Proteins 235
- 12.3.1 Antioxidants 235
- 12.3.2 Enzymes 236
- 12.3.3 Proteins 236
- 12.4 Release of Extracellular Products by Cells of Cyanobacteria Algae and Crop Plants Under Salt Stress: Amino Acids, Osmolytes, Nitrogen Nitric Oxide Ammonia 236
- 12.4.1 Amino Acids 237
- 12.4.2 Osmolytes 237
- 12.4.3 Nitrogen and Its Derivatives 237
- 12.5 Release of Extracellular Products by Cells of Cyanobacteria and Crop Plants Under Salt Stress: Phenols, Terpenoid, Phytols, Sterols, Fatty Acids 238
- 12.5.1 Phenols 238
- 12.5.2 Terpenoid 238
- 12.5.3 Phytols 239
- 12.5.4 Sterols 239

- 12.5.5 Fatty Acids 240
- 12.6 Release of Extracellular Products by Cells of Cyanobacteria and Crop Plants Under Salt Stress: Photoprotective Compounds, Polysaccharides, Halogenated Compounds, and Phytohormone 240
- 12.6.1 Photoprotective Compounds 240
- 12.6.2 Polysaccharides and Halogenated Compounds 241
- 12.6.3 Phytohormone 241
- 12.7 Uncovering Potential and Applications of Extracellular Signaling Products in Biology, Agriculture, and Medicine Current Status and Future Prospects 242
- 12.8 Current Status and Future Prospective 243 References 243

Index 252