UV-B Radiation: From Environmental Stressor to Regulator of Plant Growth

Edited by

Vijay Pratap Singh Chhattisgarh, India

Samiksha Singh Allahabad, India

Sheo Mohan Prasad Allahabad, India

Parul Parihar Allahabad, India

WILEY Blackwell

Contents

List of Contributors xvPreface xix

1 An Introduction to UV-B Research in Plant Science 1

Rachana Singh, Parul Parihar, Samiksha Singh, MPVVB Singh, Vijay Pratap Singh and Sheo Mohan Prasad

- 1.1 The Historical Background 1
- 1.2 Biologically Effective Irradiance 2
- 1.3 UV-B-induced Effects in Plants 3
- 1.4 Conclusion and Future Perspectives 5

Acknowledgements 6

- 2 Stimulation of Various Phenolics in Plants Under Ambient UV-B Radiation 9 Marija Vidović, Filis Morina and Sonja Veljović Jovanović
- 2.1 Introduction 9
- 2.2 UV-B Radiation 10
- 2.3 Phenolics 12
- 2.3.1 Chemistry of Phenolic Compounds 13
- 2.3.2 Biosynthesis and Subcellular Localization of Phenolics 13
- 2.3.3 Functions of Phenolic Compounds Depend on Their Localization 15
- 2.4 UV-B Radiation Stimulates Phenolic Induction 18
- 2.4.1 Mechanisms of UV-B Perception 18
- 2.4.2 UV-B-Induced Accumulation of Phenolic Compounds 20
- 2.4.3 Interactive Effects of UV-B with UV-A Radiation and PAR on Phenolics Accumulation 29
- 2.4.4 Interactive Effects of UV-B Radiation with other Environmental Factors on Phenolics Accumulation 30
- 2.5 UV-B-Induced Photomorphological Responses 31
- 2.5.1 Connection Between UV-B-Induced Morphological Responses and Phenolics 32
- 2.5.2 Effect of UV-B Radiation on Root Morphology in Relation to Phenolics 33
- 2.6 Photosynthesis Under UV-B Radiation 33
- 2.6.1 Interplay of Phenolics and Photosynthesis Under UV-B Radiation 34

2.7 UV-B Radiation Induces Phenolics Accumulation in Fruits 37

2.8 Conclusion and Future Perspectives 38

References 39

- 3 UV-B Radiation: A Reassessment of its Impact on Plants and Crops 57 Krystyna Żuk-Gołaszewska
- 3.1 Introduction 57
- 3.2 Plant Production 58
- 3.3 Plant Protection Against UV-B 60

References 60

- 4 Interaction of UV-B with the Terrestrial Ecosystem 65 Rohit Kumar Mishra, Sanjesh Tiwari and Sheo Mohan Prasad
- 4.1 Introduction 65
- 4.2 Growth and Development 66
- 4.3 Secondary Metabolites 67
- 4.4 Susceptibility to Herbivorous Insects 67
- 4.5 Plant Sexual Reproduction 67
- 4.6 Genomic Level 68
- 4.7 Conclusion 69

References 70

- 5 A Review on Responses of Plants to UV-B Radiation Related Stress 75 Sonika Sharma, Soumya Chatterjee, Sunita Kataria, Juhie Joshi, Sibnarayan Datta, Mohan G Vairale and Vijay Veer
- 5.1 Introduction 75
- 5.2 Morphological and Yield Response to UV-B 76
- 5.3 Targets of UV-B in the Carbon Fixation Cycle 79
- 5.4 Photoreceptors and Signalling Pathway in Response to UV-B Radiation 80
- 5.5 Acclimatization and Protection in Response to UV-B 82
- 5.6 Oxidative Stress and Antioxidant System in Response to UV-B 82
- 5.7 DNA Damage and Repair Mechanism 83
- 5.8 Exclusion of UV Components: Experimental Approach to Study the Effect on Plants 85
- 5.9 Conclusion and Future Perspectives 86

Acknowledgement 87

References 87

- 6 Oxidative Stress and Antioxidative Defence System in Plants in Response to UV-B Stress 99 Sunita Kataria
- 6.1 Introduction 99
- 6.2 Plant Protection Against UV Radiation 101
- 6.3 UV-B and ROS 103
- 6.4 UV-B and Antioxidant Enzymes 104
- 6.5 UV-B and Antioxidant 107
- 6.6 UV-B and Signalling 108
- 6.7 Conclusion and Future Perspectives 110

7 Major Influence on Phytochrome and Photosynthetic Machinery Under UV-B Exposure 123

Anita Singh, Gausiya Bashri and Sheo Mohan Prasad

- 7.1 Introduction *123*
- 7.2 Photomorphogenesis in Higher Plants 124
- 7.2.1 Phytochrome System and its Interaction with UV-B 124
- 7.2.2 Photomorphogenic Responses of UV-B 125
- 7.2.3 UV-B Signal Transduction (UVR8) 127
- 7.3 Effect of UV-B Exposure on Photosynthetic Machinery 128
- 7.3.1 Direct Effects of UV- B on Photosynthetic Machinery 128
- 7.3.1.1 Effects of UV-B Stress on Components Involved in Light Reaction 128
- 7.3.1.2 Effect of UV-B Stress on Photosystems and Cytochrome b6/f Complex 129
- 7.3.2 Indirect Effect of UV-B Stress on Components Involved in Dark Reaction 132
- 7.3.2.1 Impact on Regulation of Stomata and Rubisco Enzyme 132
- 7.3.3 UV-B induced ROS Production in Plants 133
- 7.3.4 Protective Adaptation 133
- 7.4 Conclusion and Future Perspectives 135

References 136

8 UV-B Radiation-Induced Damage of Photosynthetic Apparatus of Green Leaves: Protective Strategies *vis-a-vis* Visible and/or UV-A Light 143

Padmanava Joshi

- 8.1 Introduction 143
- 8.2 UV-B Effects on the Photosynthetic Apparatus of Leaves 143
- 8.3 UV-A Effects on Photosynthetic Apparatus of Leaves (Damage and Promotion) *145*
- 8.4 UV-A-Mediated Modulation of UV-B-Induced Damage 145
- 8.5 PAR-Mediated Balancing of UV-B-Induced Damage 146
- 8.6 Photosynthetic Adaptation and Acclimation to UV-B Radiation 146
- 8.7 Corroboration with Sensible Approach 147
- 8.8 Conclusion 149

Acknowledgements 149

References 149

9 Ultraviolet Radiation Targets in the Cellular System: Current Status and Future Directions 155

Parul Parihar, Rachana Singh, Samiksha Singh, MPVVB Singh, Vijay Pratap Singh and Sheo Mohan Prasad

- 9.1 Introduction 155
- 9.2 Absorption Characteristics of Biomolecules 156
- 9.3 Action Spectrum 156
- 9.4 Targets of UV-B 157
- 9.4.1 Interaction with Nucleic acids 157
- 9.4.1.1 Deoxyribonucleic Acids 158
- 9.4.1.2 Ribonucleic Acids 159

- 9.4.2 Proteins 159
- 9.4.2.1 Tryptophan (Trp) 160
- 9.4.2.2 Tyrosine (Tyr) 160
- 9.4.2.3 Phenylalanine (Phe) 162
- 9.4.2.4 Histidine (His) 162
- 9.5 The Photosynthetic Machinery *163*
- 9.5.1 Photosystem I and II 164
- 9.5.2 The Light-Harvesting Complexes 165
- 9.6 Cell Division and Expansion 167
- 9.7 Conclusion and Future Perspectives *168*
- Acknowledgements 169

References 169

10 Silicon: A Potential Element to Combat Adverse Impact of UV-B in Plants 175

Durgesh Kumar Tripathi, Shweta, Shweta Singh, Vaishali Yadav, Namira Arif, Swati Singh, Nawal Kishor Dubey and Devendra Kumar Chauhan

- 10.1 Introduction 175
- 10.2 The Role of Silicon Against UV-B Exposure on Morphology of Plants *178*
- 10.3 The Defensive Role of Silicon Against UV-B Exposure on Physiological and Biochemical Traits of Plants *179*
- 10.4 Silicon Repairs Anatomical Structures of Plants Damaged by UV-B Exposures 180
- 10.5 UV-B-induced Oxidative Stress and Silicon Supplementation in Plants *181*
- 10.6 Silicon Supplementation and the Status of Antioxidant Enzymes in Plants Exposed to UV-B *183*
- 10.7 Silicon and Level of Phenolic Compounds Under UV-B Stress 184
- 10.8 Conclusion and Future Perspectives 186
- References 187

11Sun-Screening Biomolecules in Microalgae:
Role in UV-Photoprotection197
Rajesh P Rastogi, Ravi R Sonani, Aran Incharoensakdi
and Datta Madamwar

- 11.1 Introduction 197
- 11.2 Global Climate Change and UV Radiation 198
- 11.3 Effects of UV Radiation on Microalgae 199
- 11.4 UV-induced Defence Mechanisms 201
- 11.5 Sun-Screening Biomolecules as Key UV Photoprotectants 201
- 11.5.1 Mycosporine-Like Amino Acids (MAAs) 202
- 11.5.2 Scytonemin 204
- 11.6 UV-Induced Biosynthesis 206
- 11.7 Photoprotective Function 207
- 11.8 Conclusion 208

Acknowledgements 208

12 Plant Response: UV-B Avoidance Mechanisms 217 Sunil K Gupta, Marisha Sharma, Farah Deeba and Vivek Pandey 12.1 Introduction 217 12.2 Ultraviolet Radiation: Common Source, Classification and Factors 219 12.2.1Common Sources of UVR 219 12.2.2 Classification 219 12.2.3 Environmental Factors Affecting UV Level 220 12.3 UV-B and Human Health 220 12.3.1 Effects on the Skin 220 12.3.2 Effects on the Eyes 220 12.4 UV-B and Plant Responses 220 12.4.1 Morphological Responses 22012.4.1.1 Visible Symptoms 220 12.4.1.2 Plant Growth and Leaf Phenology 221 12.4.1.3 Reproductive Morphology 222 12.4.1.4 UV-B-induced photomorphogenesis 222 12.4.2 Leaf Ultrastructure and Anatomy 222 12.4.3 Crop Yield 223 12.4.4 Photosynthesis 225 12.4.4.1 Pigments 225 12.4.4.2 Photosynthetic Machinery 225 12.4.5 **Biochemical Responses** 226 12.4.5.1 ROS Production in Plants 226 12.4.5.2 Free Radical Scavenging Mechanism 227 12.4.6 Molecular Responses 227 12.4.6.1 UV-B and Genes 227 Genes Damaged by UV Radiation 228 12.4.6.1.1 12.4.6.1.2 DNA Damage 228 12.4.6.2 UV and Proteins 230 12.4.6.2.1 Amino acids 231 UV-B Avoidance and Defence Mechanism 234 12.5 12.5.1Avoidance at Morphological Level 234 12.5.1.1 Epicuticular Waxes 234 12.5.2 Avoidance at Biochemical Level 235 Possible Role of Pectin Endocytosis in UV-B Avoidance 235 12.5.2.1 12.5.3 Avoidance at the Molecular Level 236 12.5.3.1 DNA Repair 236 12.5.3.2 Genes and Avoidance 237 12.5.3.3 UV-B perceived by UVR8 Strongly Inhibits Shade Avoidance 237 UV-B and Secondary Metabolites 238 12.5.4Plant Phenolics 238 12.5.4.1 12.5.4.2 Anthocyanin 239 12.5.4.3 Alkaloids 240 Isoprenoids 240 12.5.4.4 12.5.4.5 Glucosinolates 240 12.6 UV-B and its Significance 24012.6.1 Ecological Significance 240 12.6.2 UV-B and Plant Competition 241

12.7Conclusion and Future Perspectives 242 Acknowledgments 243

References 244

- 13 Impact of UV-B Exposure on Phytochrome and Photosynthetic Machinery: From Cyanobacteria to Plants 259 Shivam Yadav, Alok Kumar Shrivastava, Chhavi Agrawal, Sonia Sen, Antra Chatterjee, Shweta Rai, Ruchi Rai, Shilpi Singh and LC Rai 13.1Introduction 259 13.2Effect of UV-B Irradiation on Photosynthetic Machinery of Cyanobacteria 260 13.2.1 Pigments 260 13.2.2 Photosynthetic Electron Transport System 261 13.2.3 Photophosphorylation and CO₂ Fixation 26213.3 Effect of UV-B Irradiation on Photosynthetic Machinery of Algae 262 Effect of UV-B Irradiation on Photosynthetic Machinery of Higher Plants 13.4264 13.4.1 Pigments 264 13.4.1.1 Phytochrome 264 13.4.1.2 Chlorophylls, Carotenoids and Other Pigments 265 13.4.2 Photosystem II 265 13.4.2.1 Oxygen-evolving Complex 266 13.4.2.2 Plastoquinones and Redox-active Tyrosines 266 13.4.2.3 D1 and D2 Proteins 267 13.4.3 Photosystem I 267 13.4.4Cytochrome b6/f Complex, ATP Synthase and Rubisco 26713.4.5 Net Photosynthesis 268 13.5 **Conclusion and Future Perspectives** 268 Acknowledgements 268References 269 14 Discovery of UVR8: New Insight in UV-B Research 279 Shivam Yadav and Neelam Atri 14.1Introduction 279 14.2Photoperception in Plants 280 14.3 Discovery of UVR8: UV-B Photoreceptor 280 14.4UVR8 Structure 281 14.4.1Salt Bridge Interactions Mediate UVR8 Dimerization 281
- 14.4.2Chromophore and Key Tryptophan Residues 281
- 14.5Physiological Roles of UVR8 283
- 14.5.1 Photomorphogenic Response Regulation by UVR8 283
- 14.5.2 **Regulation of Flavonoid Biosynthesis** 284
- 14.5.3 Plant-Pathogen and Plant-Herbivore Interactions 284
- 14.6 **Conclusion and Future Perspectives** 284

- **15 UVR8 Signalling, Mechanism and Integration with other Pathways** 289 Antra Chatterjee, Alok Kumar Shrivastava, Sonia Sen, Shweta Rai, Shivam Yadav, Ruchi Rai, Shilpi Singh and LC Rai
- 15.1 Introduction 289
- 15.2 UVR8-Arbitrated Signalling 290
- 15.2.1 Constitutively Photomorphogenic 1 (COP1) 290
- 15.2.2 Elongated Hypocotyl 5 (HY5) and HYH 291
- 15.2.3 Repressor of UV-B Photomorphogenesis 1 (RUP1) and RUP2 292
- 15.3 Molecular Mechanism of Photoreceptor-Mediated Signalling 293
- 15.4 UVR8 Involvements in Different Pathways 296
- 15.4.1 Protection from Photo-Inhibition and Photo Oxidative Stress 297
- 15.4.2 Flavonoid and Alkaloid Pathways 298
- 15.4.3 DNA Damage Repair 299
- 15.4.4 Defence Against Pathogens 299
- 15.4.5 Inhibition of Plant Shade Avoidance 300
- 15.4.6 Regulation of Leaf Morphogenesis 300
- 15.4.7 Regulation of Root Growth and Development 300
- 15.4.8 Circadian Clock 301
- 15.5 Conclusion and Future Perspectives 301

Acknowledgements 302

References 302

Index 309