Contents

List of Contributors xv
Preface 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
References 6

2 Stimulation of Various Phenolics in Plants Under Ambient UV-B Radiation 9
Marija Vidović, Fills 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
Contents

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-Golaszewska
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
References 111
7 Major Influence on Phytochrome and Photosynthetic Machinery Under UV-B Exposure

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

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

Parul Parihar, Rachana Singh, Samiksha Singh, MPVV 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
### Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.4.2</td>
<td>Proteins</td>
</tr>
<tr>
<td>9.4.2.1</td>
<td>Tryptophan (Trp)</td>
</tr>
<tr>
<td>9.4.2.2</td>
<td>Tyrosine (Tyr)</td>
</tr>
<tr>
<td>9.4.2.3</td>
<td>Phenylalanine (Phe)</td>
</tr>
<tr>
<td>9.4.2.4</td>
<td>Histidine (His)</td>
</tr>
<tr>
<td>9.5</td>
<td>The Photosynthetic Machinery</td>
</tr>
<tr>
<td>9.5.1</td>
<td>Photosystem I and II</td>
</tr>
<tr>
<td>9.5.2</td>
<td>The Light-Harvesting Complexes</td>
</tr>
<tr>
<td>9.6</td>
<td>Cell Division and Expansion</td>
</tr>
<tr>
<td>9.7</td>
<td>Conclusion and Future Perspectives</td>
</tr>
<tr>
<td>10</td>
<td>Silicon: A Potential Element to Combat Adverse Impact of UV-B in Plants</td>
</tr>
<tr>
<td>10.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>10.2</td>
<td>The Role of Silicon Against UV-B Exposure on Morphology of Plants</td>
</tr>
<tr>
<td>10.3</td>
<td>The Defensive Role of Silicon Against UV-B Exposure on Physiological and Biochemical Traits of Plants</td>
</tr>
<tr>
<td>10.4</td>
<td>Silicon Repairs Anatomical Structures of Plants Damaged by UV-B Exposures</td>
</tr>
<tr>
<td>10.5</td>
<td>UV-B-induced Oxidative Stress and Silicon Supplementation in Plants</td>
</tr>
<tr>
<td>10.6</td>
<td>Silicon Supplementation and the Status of Antioxidant Enzymes in Plants Exposed to UV-B</td>
</tr>
<tr>
<td>10.7</td>
<td>Silicon and Level of Phenolic Compounds Under UV-B Stress</td>
</tr>
<tr>
<td>10.8</td>
<td>Conclusion and Future Perspectives</td>
</tr>
<tr>
<td>11</td>
<td>Sun-Screening Biomolecules in Microalgae: Role in UV-Photoprotection</td>
</tr>
<tr>
<td>11.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>11.2</td>
<td>Global Climate Change and UV Radiation</td>
</tr>
<tr>
<td>11.3</td>
<td>Effects of UV Radiation on Microalgae</td>
</tr>
<tr>
<td>11.4</td>
<td>UV-induced Defence Mechanisms</td>
</tr>
<tr>
<td>11.5</td>
<td>Sun-Screening Biomolecules as Key UV Photoprotectants</td>
</tr>
<tr>
<td>11.5.1</td>
<td>Mycosporine-Like Amino Acids (MAAs)</td>
</tr>
<tr>
<td>11.5.2</td>
<td>Scytonemin</td>
</tr>
<tr>
<td>11.6</td>
<td>UV-Induced Biosynthesis</td>
</tr>
<tr>
<td>11.7</td>
<td>Photoprotective Function</td>
</tr>
<tr>
<td>11.8</td>
<td>Conclusion</td>
</tr>
<tr>
<td></td>
<td>Acknowledgements</td>
</tr>
<tr>
<td></td>
<td>References</td>
</tr>
</tbody>
</table>
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
12.2.1 Common 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 220
12.4.1.1 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
12.4.6.1.1 Genes Damaged by UVRadiation 228
12.4.6.1.2 DNA Damage 228
12.4.6.2 UV and Proteins 230
12.4.6.2.1 Amino acids 231
12.5 UV-B Avoidance and Defence Mechanism 234
12.5.1 Avoidance at Morphological Level 234
12.5.1.1 Epicuticular Waxes 234
12.5.2 Avoidance at Biochemical Level 235
12.5.2.1 Possible Role of Pectin Endocytosis in UV-B Avoidance 235
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
12.5.4 UV-B and Secondary Metabolites 238
12.5.4.1 Plant Phenolics 238
12.5.4.2 Anthocyanin 239
12.5.4.3 Alkaloids 240
12.5.4.4 Isoprenoids 240
12.5.4.5 Glucosinolates 240
12.6 UV-B and its Significance 240
12.6.1 Ecological Significance 240
12.6.2 UV-B and Plant Competition 241
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 L C Rai
13.1 Introduction 259
13.2 Effect 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 262
13.3 Effect of UV-B Irradiation on Photosynthetic Machinery of Algae 262
13.4 Effect of UV-B Irradiation on Photosynthetic Machinery of Higher Plants 264
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
13.4.4 Cytochrome b6/f Complex, ATP Synthase and Rubisco 267
13.4.5 Net Photosynthesis 268
13.5 Conclusion and Future Perspectives 268
Acknowledgements 268
References 269

14 Discovery of UVR8: New Insight in UV-B Research 279
Shivam Yadav and Neelam Atri
14.1 Introduction 279
14.2 Photoperception in Plants 280
14.3 Discovery of UVR8: UV-B Photoreceptor 280
14.4 UVR8 Structure 281
14.4.1 Salt Bridge Interactions Mediate UVR8 Dimerization 281
14.4.2 Chromophore and Key Tryptophan Residues 281
14.5 Physiological 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
References 285
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