

PROTECTIVE CHEMICAL AGENTS IN

THE AMELIORATION OF PLANT ABIOTIC STRESS

BIOCHEMICAL AND MOLECULAR PERSPECTIVES



EDITED BY
ARYADEEP ROYCHOUHDURY
DURGESH KUMAR TRIPATHI

WILEY Blackwell

Table of Contents

[Cover](#)

[List of Contributors](#)

[1 Role of Proline and Glycine Betaine in Overcoming Abiotic Stresses](#)

[1.1 Introduction](#)

[1.2 Responses of Crop Plants Under Abiotic Stresses](#)

[1.3 Mechanisms of Osmoprotectant Functions in Overcoming Stress](#)

[1.4 Application of Osmoprotectants in Stress Conditions](#)

[1.5 Conclusion and Future Perspectives](#)

[Acknowledgment](#)

[References](#)

[2 Glycine Betaine and Crop Abiotic Stress Tolerance: An Update](#)

[2.1 Introduction](#)

[2.2 Biosynthesis of GB](#)

[2.3 Accumulation of GB Under Abiotic Stress in Crop Plants](#)

[2.4 Exogenous Application of GB in Crop Plants Under Abiotic Stress](#)

[2.5 Transgenic Approach to Enhance GB Accumulation in Crop Plants Under Abiotic Stress](#)

[2.6 Effect of GB on Reproductive Stage in Different Crops](#)

[2.7 Pyramiding GB Synthesizing Genes for Enhancing Abiotic Stress Tolerance in Plants](#)

[2.8 Conclusion and Future Prospective](#)

[Acknowledgment](#)

[Reference](#)

[3 Osmoprotective Role of Sugar in Mitigating Abiotic Stress in Plants](#)

[3.1 Introduction](#)

[3.2 Involvement of Sugar in Plant Developmental Process](#)

[3.3 Multidimensional Role of Sugar Under Optimal and Stressed Conditions](#)

[References](#)

[4 Sugars and Sugar Polyols in Overcoming Environmental Stresses](#)

[4.1 Introduction](#)

[4.2 Types of Sugars and Sugar Alcohols](#)

[4.3 Mechanism of Action of Sugars and Polyols](#)

[4.4 Involvement of Sugars and Polyols in Abiotic Stress Tolerance](#)

[4.5 Engineering Abiotic Stress Tolerance Using Sugars and Sugar Alcohols](#)

[4.6 Conclusions and Future Perspectives](#)

[References](#)

[5 Ascorbate and Tocopherols in Mitigating Oxidative Stress](#)

[5.1 Introduction](#)

[5.2 Role of Ascorbic Acid in Plant Physiological Processes](#)

[5.3 Transgenic Approaches for Overproduction of Ascorbate Content for Fight Against Abiotic Stress](#)

[5.4 Conclusion](#)

[References](#)

[6 Role of Glutathione Application in Overcoming Environmental Stress](#)

[6.1 Introduction](#)

[6.2 Glutathione Molecular Structure](#)

[6.3 Glutathione Biosynthesis and Distribution](#)

[6.4 Glutathione-induced Oxidative Stress Tolerance](#)

[6.5 Impact of Abiotic Stress on Glutathione Content in Various Plants](#)

[6.6 Exogenous Application of GSH in Plants](#)

[6.7 Cross Talk on Glutathione Signaling Under Abiotic Stress](#)

[6.8 Conclusion](#)

[References](#)

[7 Modulation of Abiotic Stress Tolerance Through Hydrogen Peroxide](#)

[7.1 Introduction](#)

[7.2 Abiotic Stress in Crop Plants](#)

[7.3 Mechanisms of Hydrogen Peroxide in Cells](#)

[7.4 Role of Hydrogen Peroxide in Overcoming Stress](#)

[7.5 Conclusion and Future Perspectives](#)

[Acknowledgment](#)

[References](#)

[8 Exogenous Nitric Oxide- and Hydrogen Sulfide-induced Abiotic Stress Tolerance in Plants](#)

[8.1 Introduction](#)

[8.2 Nitric Oxide Biosynthesis in Plants](#)

[8.3 Hydrogen Sulfide Biosynthesis in Plants](#)

[8.4 Application Methods of NO and H₂S Donors in Plants](#)

[8.5 Exogenous NO-induced Abiotic Stress Tolerance](#)

[8.6 Conclusions and Outlook](#)

[References](#)

[9 Role of Nitric Oxide in Overcoming Heavy Metal Stress](#)

[9.1 Introduction](#)

[9.2 Nitric Oxide and Osmolyte Synthesis During Heavy Metal Stress](#)

[9.3 Relation of Nitric Oxide and Secondary Metabolite Modulation in Heavy Metal Stress](#)

[9.4 Regulation of Redox Regulatory Mechanism by Nitric Oxide](#)

[9.5 Nitric Oxide and Hormonal Cross Talk During Heavy Metal Stress](#)

[9.6 Conclusion](#)

[References](#)

[10 Protective Role of Sodium Nitroprusside in Overcoming Diverse Environmental Stresses in Plants](#)

[10.1 Introduction](#)

[10.2 Role of SNP in Alleviating Abiotic Stress](#)

[10.3 Conclusion and Future Prospect](#)

[Acknowledgments](#)

[References](#)

[11 Role of Growth Regulators and Phytohormones in Overcoming Environmental Stress](#)

[11.1 Introduction](#)

[11.2 Function of Classical Plant Hormones in Stress Mitigation](#)

[11.3 Role of Specialized Stress-responsive Hormones](#)

[11.4 Hormone Cross Talk and Stress Alleviation](#)

[11.5 Conclusions and Future Perspective](#)

[References](#)

[12 Abscisic Acid Application and Abiotic Stress Amelioration](#)

[12.1 Introduction](#)

[12.2 Abscisic Acid Biosynthesis](#)

[12.3 Role of Abscisic Acid in Plant Stress Tolerance](#)

[12.4 Regulation of ABA Biosynthesis Through Abiotic Stress](#)

[12.5 ABA and Abiotic Stress Signaling](#)

[12.6 Drought Stress](#)

[12.7 UV-B Stress](#)

[12.8 Water Stress](#)

[12.9 ABA and Transcription Factors in Stress Tolerance](#)

[12.10 Conclusion](#)

[References](#)

[13 Role of Polyamines in Mitigating Abiotic Stress](#)

[13.1 Introduction](#)

[13.2 Distribution and Function of Polyamines](#)

[13.3 Synthesis, Catabolism, and Role of Polyamines](#)

[13.4 Polyamines and Abiotic Stress](#)

[13.5 Conclusion](#)

[References](#)

[14 Role of Melatonin in Amelioration of Abiotic Stress-induced Damages](#)

[14.1 Introduction](#)

[14.2 Melatonin Biosynthesis in Plants](#)

[14.3 Modulation of Melatonin Levels in Plants Under Stress Conditions](#)

[14.4 Role of Melatonin in Amelioration of Stress-induced Damages](#)

[14.5 Mechanisms of Melatonin-mediated Stress Tolerance](#)

[14.6 Conclusion](#)

[References](#)

[15 Brassinosteroids in Lowering Abiotic Stress-mediated Damages](#)

[15.1 Introduction](#)

[15.2 BR-induced Stress Tolerance in Plants](#)

[15.3 Conclusions and Future Perspectives](#)

[References](#)

[16 Strigolactones in Overcoming Environmental Stresses](#)

[16.1 Introduction](#)

[16.2 Various Roles of SLs in Plants](#)

[16.3 Cross Talk Between Other Phytohormones and SLs](#)

[16.4 Conclusion](#)

[References](#)

[17 Emerging Roles of Salicylic Acid and Jasmonates in Plant Abiotic Stress Responses](#)

[17.1 Introduction](#)

[17.2 Salicylic Acid](#)

[17.3 Biosynthesis and Metabolism of SA](#)

[17.4 SA in Abiotic Stress Tolerance](#)

[17.5 Signaling of SA Under Abiotic Stress](#)

[17.6 Jasmonic Acid](#)

[17.7 Physiological Function of Jasmonates](#)

[17.8 Biosynthesis of Jasmonic Acid](#)

[17.9 JA Signaling in Plants](#)

[17.10 JA and Abiotic Stress](#)

[17.11 Role of Jasmonates in Temperature Stress](#)

[17.12 Metal Stress and Role of Jasmonates](#)

[17.13 Jasmonates and Salt Stress](#)

[17.14 Jasmonates and Water Stress](#)

[17.15 Cross Talk Between JA and SA Under Abiotic Stress](#)

[17.16 Concluding Remarks](#)

[Acknowledgments](#)

[References](#)

[18 Multifaceted Roles of Salicylic Acid and Jasmonic Acid in Plants Against Abiotic Stresses](#)

[18.1 Introduction](#)

[18.2 Biosynthesis of SA and JA](#)

[18.3 Exogenous Application of SA and JA in Abiotic Stress Responses](#)

[18.4 Future Goal and Concluding Remarks](#)

[References](#)

[19 Brassinosteroids and Salicylic Acid as Chemical Agents to Ameliorate Diverse Environmental Stresses in Plants](#)

[19.1 Introduction](#)

[19.2 Overview of PGRs](#)

[19.3 BRs and SA in Ameliorating Abiotic Stresses](#)

[19.4 Conclusion](#)

[References](#)

[20 Role of \$\gamma\$ -Aminobutyric Acid in the Mitigation of Abiotic Stress in Plants](#)

[20.1 Introduction](#)

[20.2 GABA Metabolism](#)

[20.3 Protective Role of GABA Under Different Stresses](#)

[20.4 Conclusion and Future Perspective](#)

[Acknowledgments](#)

[References](#)

[21 Isoprenoids in Plant Protection Against Abiotic Stress](#)

[21.1 Introduction](#)

[21.2 Synthesis of Free Radicals During Abiotic Stress Conditions](#)

[21.3 Biosynthesis of Isoprenoids in Plants](#)

[21.4 Functions and Mechanisms of Isoprenoids During Abiotic Stresses](#)

[21.5 Conclusion](#)

[Acknowledgments](#)

[References](#)

[22 Involvement of Sulfur in the Regulation of Abiotic Stress Tolerance in Plants](#)

[22.1 Introduction](#)

[22.2 Sulfur Metabolism](#)

[22.3 Sulfur Compounds Having Potential to Ameliorate Abiotic Stress](#)

[22.4 Role of Sulfur Compounds During Salinity Stress](#)

[22.5 Role of Sulfur Compounds During Drought Stress](#)

[22.6 Role of Sulfur Compounds During Temperature Stress](#)

[22.7 Role of Sulfur Compounds During Light Stress](#)

[22.8 Role of Sulfur Compounds in Heavy Metal Stress](#)

[22.9 Conclusion and Future Perspectives](#)

[Acknowledgments](#)

[References](#)

[23 Role of Thiourea in Mitigating Different Environmental Stresses in Plants](#)

[23.1 Introduction](#)

[23.2 Modes of TU Application](#)

[23.3 Biological Roles of TU Under Normal Conditions](#)

[23.4 Role of Exogenous Application of TU in Mitigation of Environmental Stresses](#)

[23.5 Mechanisms of TU-mediated Enhanced Stress Tolerance](#)

[23.6 Success Stories of TU Application at Field Level](#)

[23.7 Conclusion](#)

[References](#)

[24 Oxylipins and Strobilurins as Protective Chemical Agents to Generate Abiotic Stress Tolerance in Plants](#)

[24.1 Introduction](#)

[24.2 Signaling Mediated by Oxylipins](#)

[24.3 Roles of Oxylinins in Abiotic Stress Tolerance](#)

[24.4 Role of Strobilurins in Abiotic Stress Tolerance](#)

[24.5 Conclusion](#)

[24.6 Future Perspectives](#)

[Acknowledgments](#)

[References](#)

[25 Role of Triacontanol in Overcoming Environmental Stresses](#)

[25.1 Introduction](#)

[25.2 Environmental Stresses and Tria as a Principal Stress-Alleviating Component in Diverse Crop Plants](#)

[25.3 Assessment of Foliar and Seed Priming Tria Application in Regulating Diverse Physio-biochemical Traits in Plants](#)

[25.4 Conclusion and Future Prospects](#)

[Acknowledgments](#)

[References](#)

[26 Penconazole, Paclobutrazol, and Triacontanol in Overcoming Environmental Stress in Plants](#)

[26.1 Introduction](#)

[26.2 Nature of Damages by Different Abiotic Stresses](#)

[26.3 Synthesis of Chemicals](#)

[26.4 Role of Exogenously Added Penconazole, Paclobutrazol, and Triacontanol During Stress](#)

[26.5 Conclusion](#)

[Acknowledgment](#)

[References](#)

27 Role of Calcium and Potassium in Amelioration of Environmental Stress in Plants

27.1 Introduction

27.2 Biological Functions of Calcium and Potassium in Plants

27.3 Calcium and Potassium Uptake, Transport, and Assimilation in Plants

27.4 Calcium- and Potassium-induced Abiotic Stress Signaling

27.5 Role of Calcium and Potassium in Abiotic Stress Tolerance

27.6 Waterlogging Conditions

27.7 High Light Intensity

27.8 Conclusion

Acknowledgments

References

28 Role of Nitric Oxide and Calcium Signaling in Abiotic Stress Tolerance in Plants

28.1 Introduction

28.2 Sources of Nitric Oxide Biosynthesis in Plants

28.3 Effects of Nitric Oxide on Plants Under Abiotic Stresses

28.4 Role of Calcium Signaling During Abiotic Stresses

References

29 Iron, Zinc, and Copper Application in Overcoming Environmental Stress

29.1 Introduction

29.2 Iron

29.3 Zinc

[29.4 Copper](#)

[29.5 Conclusion](#)

[References](#)

[30 Role of Selenium and Manganese in Mitigating Oxidative Damages](#)

[30.1 Introduction](#)

[30.2 Factors Augmenting Oxidative Stress](#)

[30.3 Effects of Heavy Metals on Plants](#)

[30.4 Role of Manganese \(Mn\) in Controlling Oxidative Stress](#)

[30.5 Role of Selenium \(Se\) in Controlling Oxidative Stress](#)

[30.6 Role of Antioxidants in Counteracting ROS](#)

[30.7 Role of Se in Re-establishing Cellular Structure and Function](#)

[30.8 Conclusion](#)

[Acknowledgment](#)

[References](#)

[31 Role of Silicon Transportation Through Aquaporin Genes for Abiotic Stress Tolerance in Plants](#)

[31.1 Introduction](#)

[31.2 Aquaporins](#)

[31.3 Molecular Mechanism of Water and Si Transportation Through Aquaporins](#)

[31.4 AQP Gating Influx/Outflux](#)

[31.5 Si-induced AQP Trafficking](#)

[31.6 Roles of Aquaporins in Plant-Water Relations Under Abiotic Stress](#)

[31.7 Role of Silicon in Abiotic Stress Tolerance](#)

[31.8 Si-mediated Drought Tolerance Through Aquaporins](#)

[31.9 Si-mediated Salinity Tolerance Through Aquaporins](#)

[31.10 Si-mediated Oxidative Tolerance Through Aquaporins](#)

[31.11 Si Mediated Signal Transduction Pathway Under Biotic Stress](#)

[31.12 Conclusion](#)

[References](#)

[32 Application of Nanoparticles in Overcoming Different Environmental Stresses](#)

[32.1 Introduction](#)

[32.2 Physicochemical Properties of Nanoparticles](#)

[32.3 Mode of Synthesis of Nanoparticles](#)

[32.4 Types of Nanoparticles and Their Role in Stress Acclimation](#)

[32.5 Types of Environmental Stresses](#)

[32.6 Possible Protective Mechanism of Nanoparticles](#)

[32.7 Conclusion and Future Perspectives](#)

[References](#)

[Index](#)

[End User License Agreement](#)

List of Tables

Chapter 1

[Table 1.1 Exogenous applications of osmoprotectants in crop plants exposed to...](#)

Chapter 2

[Table 2.1 Exogenous application of glycine betaine \(GB\) and enhancing abiotic...](#)

[Table 2.2 Transgenics plants developed from glycine betaine \(GB\) biosynthetic...](#)

Chapter 3

[Table 3.1 Sugars and their associated genes to stress tolerance in various cr...](#)

Chapter 4

[Table 4.1 Role of different sugars and sugar polyols under various abiotic st...](#)

[Table 4.2 List of transgenic plants engineered for abiotic stress tolerance u...](#)

Chapter 5

[Table 5.1 Transgenic plants overproducing L-ascorbate.](#)

Chapter 6

[Table 6.1 Effect of exogenous glutathione application on plants under abiotic...](#)

Chapter 7

[Table 7.1 Effects of H₂O₂ during stress development in plants.](#)

Chapter 8

[Table 8.1 Different application methods of NO and H₂S donors in plants.](#)

[Table 8.2 Exogenous NO-induced abiotic tolerance in plants.](#)

[Table 8.3 Exogenous H₂S \(NaHS\)-induced abiotic stress tolerance.](#)

Chapter 16

[Table 16.1 Effects of different stress conditions on expressions of genes rel...](#)

Chapter 17

[Table 17.1 Summary of few representative studies demonstrating the role of sa...](#)

[Table 17.2 Representative studies showing the plant responses to jasmonic aci...](#)

Chapter 18

[Table 18.1 Role of SA and JA in various abiotic stresses.](#)

Chapter 25

[Table 25.1 Effects of Tria on diverse physio-biochemical attributes of plants...](#)

Chapter 28

[Table 28.1 Effects of NO mitigating heavy metal toxicity in plants and algae.](#)

[Table 28.2 Response of plants to NO against salt stress.](#)

[Table 28.3 Response of plants to Ca²⁺ under different abiotic stresses.](#)

Chapter 29

[Table 29.1 Role of micronutrients \(Fe, Zn, and Cu\) in plants and their sympto...](#)

[Table 29.2 Foliar application of micronutrients on plants under various abiot...](#)

Chapter 32

[Table 32.1 Modes of synthesis of nanoparticles in different crops with key im...](#)

[Table 32.2 Mechanisms of ameliorative action of nanoparticles in different cr...](#)

List of Illustrations

Chapter 3

[Figure 3.1 Schematic diagram of sugar signals, receptors, and signal transmi...](#)

Chapter 4

[Figure 4.1 Schematic representation of the biosynthesis of various types of ...](#)

Chapter 5

[Figure 5.1 Ascorbic acid.](#)

[Figure 5.2 Ascorbic acid biosynthetic cycle and interaction with ROS.](#)

[Figure 5.3 Tocopherol.](#)

[Figure 5.4 Tocopherol and ROS interplay.](#)

[Figure 5.5 Tocopherol-ascorbate-glutathione triad.](#)

Chapter 6

[Figure 6.1 Molecular structure of glutathione.](#)

[Figure 6.2 Biosynthesis and metabolism of glutathione. First step occurs in ...](#)

[Figure 6.3 The ascorbate-glutathione \(AsA-GSH\) cycle occurring in the cell. ...](#)

[Figure 6.4 Diagrammatic representation of GSH-stimulated signal transduction...](#)

Chapter 7

[Figure 7.1 Role and signaling mechanisms of H₂O₂ under abiotic/biotic stress...](#)

[Figure 7.2 Types of H₂O₂-priming for plant stress tolerance.](#)

Chapter 8

[Figure 8.1 An overview of NO biosynthesis in higher plants. Nitrate reductas...](#)

[Figure 8.2 Generalized model of H₂S b...](#)

Chapter 9

[Figure 9.1 A schematic model showing nitric oxide \(NO\)-mediated heavy metal ...](#)

Chapter 11

[Figure 11.1 A schematic diagram depicting phytohormone-mediated stress allev...](#)

Chapter 13

[Figure 13.1 Structure of most abundant polyamines found in plants.](#)

[Figure 13.2 Polyamine biosynthetic pathway \(Sarvajeet and Narendra 2010\).](#)

[Figure 13.3 Interaction among PAs and various abiotic stress factors. Multip...](#)

Chapter 14

[Figure 14.1 Melatonin biosynthesis in plants.](#)

[Figure 14.2 Overview of functions of melatonin.](#)

Chapter 15

[Figure 15.1 Synergistic effect of exogenously applied brassinosteroids on pl...](#)

Chapter 16

[Figure 16.1 Strigolactone biosynthesis \(proposed model\) and its downstream s...](#)

Chapter 18

[Figure 18.1 SA biosynthesis pathways in different plants. Cinnamate-derived ...](#)

[Figure 18.2 Biosynthetic pathways of jasmonates.](#)

[Figure 18.3 A simplified probable mechanism of involvement of salicylic acid...](#)

Chapter 20

[Figure 20.1 Solid arrows represent the anabolic pathway and dotted arrows re...](#)

Chapter 21

[Figure 21.1 Abiotic stress generates ROS in plants that cause oxidative dama...](#)

[Figure 21.2 Biosynthetic pathways of isoprenoid. The biosynthesis of isopren...](#)

Chapter 22

[Figure 22.1 Outline of assimilation pathway of sulfur in plants.](#)

Chapter 23

[Figure 23.1 Schematic representation of mode of action of TU under different...](#)

Chapter 25

[Figure 25.1 Structural formula of triacontanol having 30 carbon atoms, 62 hy...](#)

[Figure 25.2 Triacontanol induced stress tolerance in plants. Readers are req...](#)

Chapter 26

[Figure 26.1 Physical factors responsible for abiotic stress.](#)

Chapter 27

[Figure 27.1 Network of calcium signaling in plants and important proteins in...](#)

[Figure 27.2 Abiotic stress and calcium regulation in plants.](#)

[Figure 27.3 Cell signaling associated with low potassium levels in plants.](#)

[Figure 27.4 Role of elevated potassium in various abiotic stress in plants....](#)

Chapter 28

[Figure 28.1 Protective role of NO against biotic and abiotic stresses in pla...](#)

Chapter 29

[Figure 29.1 Schematic representation of abiotic stress tolerance in plants b...](#)

Chapter 30

[Figure 30.1 Factors involved in the generation of ROS.](#)

[Figure 30.2 Distribution of SODs in the plant cell.](#)

[Figure 30.3 Overview of positive and negative roles of Se in plants.](#)

Chapter 31

[Figure 31.1 Silicon as SiO₂ enhancing plant tolerance by way of alleviating ...](#)

[Figure 31.2 Transportation mechanism of water and SiOH₄ into living tissues ...](#)

[Figure 31.3 Illustration of structural mechanism of AQPs gating in plasma me...](#)

[Figure 31.4 A schematic representation of silicon \(Si\) transport in plants. ...](#)

Chapter 32

[Figure 32.1 Methods for synthesis of nanoparticles.](#)

[Figure 32.2 Modes of entry of nanoparticles and their possible mechanisms of...](#)

Protective Chemical Agents in the Amelioration of Plant Abiotic Stress

Biochemical and Molecular Perspectives

Edited by

Aryadeep Roychoudhury

Department of Biotechnology
St. Xavier's College (Autonomous), Kolkata
Kolkata, India

Durgesh Kumar Tripathi

Amity Institute of Organic Agriculture
Amity University Uttar Pradesh
Noida, Uttar Pradesh, India

WILEY Blackwell

This edition first published 2020
© 2020 John Wiley & Sons Ltd

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

The right of Aryadeep Roychoudhury and Durgesh Kumar Tripathi to be identified as the authors of the editorial material in this work has been asserted in accordance with law.

Registered Office(s)

John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

For details of our global editorial offices, customer services, and more information about Wiley products, visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Limit of Liability/Disclaimer of Warranty

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

Library of Congress Cataloging-in-Publication Data

Names: Roychoudhury, Aryadeep, editor. | Tripathi, Durgesh Kumar, editor.

Title: Protective chemical agents in the amelioration of plant abiotic stress: biochemical and molecular perspectives / edited by Aryadeep Roychoudhury, Durgesh Kumar Tripathi.

Description: Hoboken : Wiley-Blackwell, 2020. | Includes bibliographical references and index.

Identifiers: LCCN 2019051508 (print) | LCCN 2019051509 (ebook) | ISBN 9781119551638 (hardback) | ISBN 9781119551645 (adobe pdf) | ISBN 9781119551652 (epub)

Subjects: LCSH: Plants--Effect of chemicals on--Molecular aspects. | Plants--Effect of stress on. | Plant molecular biology.

Classification: LCC QK746 .P76 2020 (print) | LCC QK746 (ebook) | DDC 581.3-dc23

LC record available at <https://lcn.loc.gov/2019051508>

LC ebook record available at <https://lcn.loc.gov/2019051509>

Cover Design: Wiley

Cover Image: © The natures/Shutterstock

List of Contributors

Ghulam Hassan Abbasi

Department of Soil Science
University College of Agriculture and Environmental
Sciences
The Islamia University of Bahawalpur
Bahawalpur
Pakistan

Krishnendu Acharya

Molecular and Applied Mycology and Plant Pathology
Laboratory
Department of Botany
University of Calcutta
Kolkata
India

Sobia Afzal

Department of Soil Science
University College of Agriculture and Environmental
Sciences
The Islamia University of Bahawalpur
Bahawalpur
Pakistan

Farhan Ahmad

Department of Bioengineering
Integral University
Lucknow
India

Haseen Ahmed

Laboratory of Photobiology and Molecular Microbiology
Centre of Advanced Study in Botany
Institute of Science

Banaras Hindu University
Varanasi
India

Haifa Abdulaziz S. Alhathloul

Biology Department
College of Science, Jouf University
Sakaka
Kingdom of Saudi Arabia

Shafaqat Ali

Department of Environmental Sciences and Engineering
Government College University Faisalabad
Allama Iqbal Road, Faisalabad
Pakistan

and

Department of Biological Sciences and Technology
China Medical University
Taichung
Taiwan

Rohaya Ali

Department of Biochemistry
University of Kashmir
Srinagar
India

Nimisha Amist

Plant Physiology Laboratory
Department of Botany
University of Allahabad
Allahabad
India

Srinivas Ankanagari

Department of Genetics
Osmania University

Hyderabad
India

Mohammad Israil Ansari

Department of Botany
University of Lucknow
Lucknow
India

Mohd. Asgher

Plant Physiology and Biochemistry Lab
Department of Botany
Baba Ghulam Shah Badshah University,
Rajouri, Jammu and Kashmir
India

Aditya Banerjee

Post Graduate Department of Biotechnology
St. Xavier's College (Autonomous)
30, Mother Teresa Sarani
Kolkata
West Bengal, India

Saswati Bhattacharya

Department of Botany
Dr. A. P. J. Abdul Kalam Govt. College
New Town, Rajarhat, West Bengal
India

Pooja Bhatnagar-Mathur

International Crops Research Institute for the Semi-Arid
Tropics (ICRISAT)
Patancheru, Hyderabad, Telangana
India

Eijaz Ahmed Bhat

Life Science Institute
Zhejiang University

Hangzhou, Zhejiang
PR China

Deepesh Bhatt

Department of Biotechnology
Shree Ramkrishna Institute of Computer Education and
Applied Sciences
Veer Narmad South Gujarat University
Surat, Gujarat
India

Megha D. Bhatt

GSFC AgroTech Ltd., Gujarat State Fertilizers & Chemicals
Ltd.
Vadodara
India

M.H.M. Borhannuddin Bhuyan

Laboratory of Plant Stress Response
Department of Applied Biological Sciences
Faculty of Agriculture, Kagawa University
Takamatsu, Kagawa
Japan

and

Citrus Research Station
Bangladesh Agricultural Research Institute
Jaintapur, Sylhet
Bangladesh

Deepak Singh Bisht

ICAR—National Research Centre on Plant biotechnology
IARI
Pusa, New Delhi
India

Syed Asad Hussain Bukhari

Department of Agronomy
Bahauddin Zakariya University

Multan
Pakistan

Naresh V. Butani

Shree Ramkrishna Institute of Computer Education and
Applied Sciences
Veer Narmad South Gujarat University
Surat, Gujarat
India

Debasis Chakrabarty

Council of Scientific and Industrial Research—National
Botanical Research Institute (CSIR—NBRI)
Rana Pratap Marg
Lucknow
India

Nilanjan Chakraborty

Department of Botany
Scottish Church College
Kolkata
India

Saket Chandra

Department of Bio-Engineering
Birla Institute of Technology
Mesra, Ranchi, Jharkhand
India

and

Gulf Coast Research & Education Center
IFAS
University of Florida
Wimauma, Florida
USA

Muhammad Danish

Department of Soil Science
University College of Agriculture and Environmental

Sciences
The Islamia University of Bahawalpur
Bahawalpur
Pakistan

Kingsuk Das
Department of Botany
Serampore College
Serampore
Hooghly, West Bengal
India

Muhammad Dawood
Department of Environmental Sciences
Bahauddin Zakariya University
Multan
Pakistan

Murat Dikilitas
Department of Plant Protection
Faculty of Agriculture
Harran University
S. Urfa
Turkey

Rachana Dudhat
Shree Ramkrishna Institute of Computer Education and
Applied Sciences
Veer Narmad South Gujarat University
Surat, Gujarat
India

Titash Dutta
Department of Biochemistry and Bioinformatics
Institute of Science
GITAM (Deemed to be University)
Visakhapatnam