Approaches for Enhancing Abiotic Stress Tolerance in Plants

EDITED BY
Mirza Hasanuzzaman • Kamrun Nahar • Masayuki Fujita
Hirosuke Oku • M. Tofazzal Islam

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Preface

In an open environment, plant growth and productivity are governed by several environmental factors that can be biotic or abiotic. Such environmental factors sometimes become very harsh to the growth and development of the plants. Global climate change is predicted to increase the frequency and intensity of environmental stresses such as salinity, drought, metal/metalloid toxicity, heat, chilling/freezing, flooding and atmospheric pollutants to plants. In the era of industrial development, some anthropogenic activities are also causing serious threats to the productivity of crops. Yield loss of crops due to abiotic stresses is higher than the loss caused by pests, diseases and weeds. Furthermore, environmental stresses to the crop plants are beyond the control of farmers. Yield loss of staple food crops can be up to 70% due to the detrimental effects of abiotic stresses.

The increasing world population, the subsequent higher demand for food and the increasing occurrence of abiotic stresses have made agriculture challenging in the 21st century. However, attempts to improve crop yield under stressful environments by improvement of plants through classical breeding have been largely unsuccessful mainly due to the multi-genic origin of the adaptive responses. Due to the physiological and genetic complexity of the stress tolerance traits, the real progress in crop breeding for stress tolerance may be achieved only via a painfully slow pyramiding of essential physiological traits. Therefore, a well-focused approach combining the molecular, physiological, biochemical and metabolic aspects of salt tolerance is essential to develop stress-tolerant crop varieties. Numerous studies indicated the factors governing the defense system in plants and the necessity to generate tolerant varieties which can acclimatize and adapt to the stressful environments without having any adverse impacts on their productivity. However, the molecular responses of plants to a combination of abiotic stresses are unique and cannot be directly extrapolated from the responses of plants alone. A large body of the literature suggested that, though with a certain degree of overlap, each stress causes a unique mechanism of response, tailored to the specific needs of the plant and that each combination of two or more different stresses may also have a specific response. The recent progress in molecular biology and genomics studies on many major crop plants are generating a wealth of information for the improvement of crop plants to abiotic stress. However, plant improvement for any abiotic stress is not merely a number of genes put together. Further progress in the field may be achieved when various omics tools are intrinsically interspersed with the precise understanding of plant function and put into an environmental context.

This book compiles the recent updates of our understanding of various approaches in conferring abiotic stress tolerance. It includes 27 chapters contributed by 110 leading experts, spanning from the diverse areas of the field of plant physiology, environmental sciences, crop science, molecular biology and biotechnology. The first chapter presents the general outline of various abiotic stresses. The impacts of climate change on crop production in the world as well as in South Asia is described in Chapter 2. Plant responses to the salt stress are described in Chapter 3. Plant responses and signaling to drought stress tolerance are reviewed in Chapters 4 and 5, respectively. Variability in physiological, biochemical and molecular mechanisms of chickpea varieties to water stress is the subject matter of Chapter 6. Chapters 7 and 8 discuss the plant responses and tolerance to cold stress and cold stress tolerance in rice, respectively. Heavy metals in soils exert toxicity to plants and remarkably reduce the yield of crops. Chapter 9 updates heavy metal toxicity in plants and its mitigation. Boron is an essential nutrient, but higher levels of boron are toxic to plants. Responses of plants to nutrient deficiency and toxicity due to higher levels of boron are focused in Chapter 10. Adaptation of plants to elevated levels of ozone is described in Chapter 11. Various hydrocarbons are known as soil contaminants. Chapter 12 reviews hydrocarbon contamination and its amelioration in soils. An overview of abiotic stress-induced oxidative damage in plants is the subject matter of Chapter 13. The roles of transcription factors in the antioxidant responses of plants under abiotic stresses are reviewed in Chapter 14. Chapter 15 discusses modern approaches to enhance antioxidant defense systems in plants. Coordination and auto-propagation of ROS signals in plants are covered in Chapter 16. Synthesis of various osmolytes in plants under abiotic stresses is critical for plant tolerance. Regulation of osmolyte syntheses and improvement of abiotic stress tolerance in plants are discussed in Chapter 17. Plasma membrane plays an important role in protecting the cell from dehydration. Chapter 18 updates the roles of plasma membrane proteins in tolerance of dehydration in the plant cell.

Trehalose metabolism and signaling is an area of emerging significance. In less than a decade, our views

on the importance of trehalose metabolism and its role in plants have gone through something of a revolution. Chapter 19 focuses on trehalose metabolism in plants under abiotic stressful environments. Proline is a small molecule biosynthesized in plants which plays a significant role in plants' tolerance to salinity and drought. The proline metabolism behavior of the durum wheat dehydrin transgenic *Arabidopsis thaliana* to salt stress is discussed in Chapter 20. Nitric oxide and polyamines have significant roles in plant tolerance to abiotic stresses. Molecular mechanisms of nitric oxide- and polyamines-induced plant tolerance to abiotic stresses are focused in Chapters 21 and 22, respectively. Molecular biological and genomic approaches broadened our understanding about the plants' responses to the abiotic stresses at molecular and genomic levels. Chapters 23 and 24 update current molecular and genomic knowledge about plants' tolerance and responses to the abiotic stresses. The hallmark attributes of plant transcription factors and the potential of WRKY, MYB and NAC in abiotic stresses are discussed in Chapter 25. Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)/Cas9 (CRISPR-associated enzyme 9) technology is becoming a faster, cheaper and precise tool for editing the genome of living organisms, including plants. It will revolutionize the engineering of crop plants, including for the enhancement of tolerance to the abiotic stresses. Chapter 26 updates current status and future prospects of CRISPR/Cas9 for engineering crop plants for abiotic stress tolerance. Plants harbor taxonomically diverse microorganisms. Plant-associated beneficial microorganisms (such as plant probiotic bacteria) play important roles in promoting abiotic stress tolerance in plants. Chapter 27 focused on the effects of various beneficial microorganisms in protecting plants from abiotic stresses. The wealth of information compiled in this volume updates our understanding the effects, mechanisms and interrelationships between and among various stresses, the defense strategies of plants to adapt to harsh environments, and the expression of genes involved in the synthesis of regulatory proteins. This fundamental knowledge and understanding is needed for the development of stress-tolerant plant varieties.

We, the editors, sincerely thank the authors for their outstanding works and timely contributions to publish this unique volume of book. We are highly thankful to Dr. Mahbub Alam, Lecturer, Department of Agriculture, Noakhali Science and Technology University, for his valuable help in formatting and incorporating editorial changes in the manuscripts. The Senior Editor (Biological Science), CRC Press Randy Brehm deserves our sincere thanks for prompt responses during the acquisition of this book. We are also thankful to other editorial staffs of CRC for precious help in formatting and incorporating editorial changes in the manuscripts. The editors and contributing authors hope that this book will be the reference of researchers for updating knowledge about the mechanisms and approaches for environmental stress tolerance.

Mirza Hasanuzzaman, Kamrun Nahar, Masayuki Fujita, Hirosuke Oku, and M. Tofazzal Islam

Editors

Mirza Hasanuzzaman is a Professor of Agronomy at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. In 2012, he received his PhD on 'Plant Stress Physiology and Antioxidant Metabolism' from the United Graduate School of Agricultural Sciences, Ehime University, Japan with the Japanese Government (MEXT) Scholarship. Later, he completed his postdoctoral research in Center of Molecular Biosciences (COMB), University of the Ryukyus, Okinawa, Japan with the Japan Society for the Promotion of Science (JSPS) postdoctoral fellowship. Subsequently, he joined as Adjunct Senior Researcher at the University of Tasmania with the Australian Government's Endeavour Research Fellowship. He joined as a Lecturer in the Department of Agronomy, Sher-e-Bangla Agricultural University in June 2006. He was promoted to Assistant Professor, Associate Professor and Professor in June 2008, June 2013 and June 2017, respectively. Prof. Hasanuzzaman has been devoting himself in research in the field of crop science, especially focused on Environmental Stress Physiology since 2004. He has been performing as team leader/principal investigator of different projects funded by World Bank, FAO, University Grants Commission of Bangladesh, Ministry of Science and Technology (Bangladesh) and so on.

Prof. Hasanuzzaman published over 100 articles in peer-reviewed journals and books. He has edited two books and written 35 book chapters on important aspects of plant physiology, plant stress responses and environmental problems in relation to plant species. These books were published by internationally renowned publishers (Springer, Elsevier, CRC Press, Wiley, etc.). His publications got over 2000 citations with h-index: 23 (according to Scopus). Prof. Hasanuzzaman is a Research supervisor of undergraduate and graduate students and supervised 20 M.S. students so far. He is the Editor and Reviewer of more than 50 peer-reviewed international journals and the recipient of Publons' Peer Review Award 2017. Hasanuzzaman is an active member of about 40 professional societies and acting as Publication Secretary of the Bangladesh Society of Agronomy. He has been honored by different authorities due to his outstanding performance in different fields like research and education. He received the World Academy of Science (TWAS) Young Scientist Award 2014. He has attended and presented 25 papers and posters in national and international conferences in different countries (USA, UK, Germany, Australia, Japan, Austria, Sweden, Russia, etc.).

Kamrun Nahar is an Associate Professor, Department of Agricultural Botany at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. She received her PhD on 'Environmental Stress Physiology of Plants' in 2016 from the United Graduate School of Agricultural Sciences, Ehime University, Japan with the Japanese Government (MEXT) Scholarship. Dr. Nahar has been involved in research with field crops, emphasizing stress physiology, since 2006. She has completed several research works and is also continuing a research project funded by Sher-e-Bangla Agricultural University Research System and the Ministry of Science and Technology (Bangladesh). She is supervising M.S. students. Dr. Nahar has published a number of articles in peer-reviewed journals and books with reputed publishers. She has published 50 articles and chapters related to plant physiology and environmental stresses with Springer, Elsevier, CRC Press, Wiley, etc. Her publications reached about 2000 citations with h-index: 22 (according to Scopus). She is involved in editorial activities and reviewer of international journals. She is an active member of about 20 professional societies. Dr. Nahar has attended different international conferences and presented ten papers and posters in national and international conferences in different countries (the United States, Australia, Japan, Austria, Russia, China, etc.).

Masayuki Fujita is a Professor in the Laboratory of Plant Stress Responses, Faculty of Agriculture, Kagawa University, Kagawa, Japan. He received his B.Sc. in Chemistry from Shizuoka University, Shizuoka, Japan and his M.Agr. and PhD in Plant Biochemistry from Nagoya University, Nagoya, Japan. His research interests include physiological, biochemical and molecular biological responses based on secondary metabolism in plants under various abiotic and biotic stresses; phytoalexin, cytochrome P450, glutathione *S*-transferase and phytochelatin; and redox reaction and antioxidants. In the last decade, his works were focused on oxidative stress and antioxidant defense in plants under environmental stress. His group investigates the role of different exogenous protectants in enhancing antioxidant defense and methylglyoxal detoxification systems in plants. He has supervised four M.S. students and 13 PhD students as main supervisor. He has about 150 publications in journals and books and has edited four books.

Hirosuke Oku is a Professor in the Center of Molecular Biosciences at the Tropical Biosphere Research Center in University of the Ryukyus, Okinawa, Japan. He obtained his Bachelor of Science in Agriculture from University of the Ryukyus in 1980. He received his PhD in Biochemistry from Kyushu University, Japan in 1985. In the same year, he started his career as Assistant Professor in the Faculty of Agriculture, University of the Ryukyus. He became Professor in 2009. He received several prestigious awards and medals including the Encouragement Award of Okinawa Research (1993) and Encouragement Award of Japanese Society of Nutrition and Food Science (1996). Prof. Oku is the group leader of the Molecular Biotechnology Group of the Center of Molecular Biosciences at University of the Ryukyus, His research works focused on lipid biochemistry; molecular aspects of phytomedicine; secondary metabolites biosynthesis and abiotic stress tolerance of tropical forest trees. He has about ten PhD students and over 20 M.S. students. Prof. Oku has over 50 peer-reviewed publications in his record.

M. Tofazzal Islam is a Professor of the Department of Biotechnology of Bangabandhu Sheikh Mujibur Rahman Agricultural University in Bangladesh. He did his M.S. and PhD in Applied Biosciences at Hokkaido University in Japan. Dr. Islam received postdoctoral research experiences at Hokkaido University, University of Goettingen, University of Nottingham and West Virginia University under the JSPS, Alexander von Humboldt, Commonwealth and Fulbright Fellowships, respectively. He published articles in many international journals and book series (>200 peer-reviewed articles, total citation 1664, h-index 22, i10-index 48; RG score 39.06). Dr. Islam was awarded many prizes and medals including the Bangladesh Academy of Science Gold Medal in 2011, University Grants Commission Bangladesh Awards in 2004 and 2008 and Best Young Scientist Award 2003 from the JSBBA. Prof. Islam is the Chief Editor of a book series, *Bacillus and Agrobiotechnology*, published by Springer. His research interests include genomics, genome editing, plant probiotics and novel biologicals, and bioactive natural products.

Contributors

Srivani S Adimulam
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Telangana, India

Madhoolika Agrawal
Laboratory of Air Pollution and Global Climate Change
Department of Botany, Institute of Science, Banaras Hindu University
Varanasi, India

S.B. Agrawal
Laboratory of Air Pollution and Global Climate Change
Department of Botany, Institute of Science, Banaras Hindu University
Varanasi, India

Christianne M. Aikins
Climate Analytics Team, Climate Services and Research Department
APEC Climate Center
Busan, Republic of Korea

Khalid Farooq Akbar
University of Lahore
Sargodha, Pakistan

Aamir Ali
Department of Botany
University of Sargodha
Sargodha, Pakistan

Imtiaz Ali Khan
Department of Agriculture
University of Swabi
Khyber Pakhtunkhwa, Pakistan

Qasim Ali
Department of Botany
Government College University Faisalabad
Faisalabad, Pakistan

Shafaqat Ali
Department of Environmental Sciences and Engineering
Government College University Faisalabad
Faisalabad, Pakistan

Shahzad Ali Shahid
Department of Chemistry
Government College University Faisalabad
Faisalabad, Pakistan

Himanshu Bariya
Department of Life Sciences
Hemchandracharya North Gujarat University
Gujarat, India

Nicolle Louise Ferreira Barros
Instituto de Ciências Biológicas
Universidade Federal do Pará
Belém, Brazil

Pragya Barua
National Institute of Plant Genome Research
Jawaharlal Nehru University Campus
New Delhi, India

Supratim Basu
New Mexico Consortium
Los Alamos, New Mexico

Pooja Bhatnagar-Mathur
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Telangana, India

Muhammad Faraz Bhatti
Atta-ur-Rahman School of Applied Biosciences
National University of Sciences and Technology
Islamabad, Pakistan

Pankaj Bhowmik
National Research Council of Canada
Saskatoon, Saskatchewan, Canada

Hassiba Bouazzi
Biotechnology and Plant Improvement Laboratory
Center of Biotechnology of Sfax, University of Sfax
Sfax, Tunisia

Faical Brini
Biotechnology and Plant Improvement Laboratory
Center of Biotechnology of Sfax, University of Sfax
Sfax, Tunisia

Nataša Čerekovič
Institute of Sciences of Food Productions
National Research Council (ISPA-CNR)
Lecce, Italy

Niranjan Chakraborty
National Institute of Plant Genome Research
Jawaharlal Nehru University Campus
New Delhi, India

Subhra Chakraborty
National Institute of Plant Genome Research
Jawaharlal Nehru University Campus
New Delhi, India

Antra Chatterjee
Laboratory of Algal Biology, Molecular Biology Section
Center of Advanced Study in Botany, Institute of Science, Banaras Hindu University
Varanasi, India

Jong Ahn Chun
Climate Analytics Team, Climate Services and Research
Department
APEC Climate Center
Busan, Republic of Korea

Shah Fahad
Department of Agriculture
University of Swabi
Khyber Pakhtunkhwa, Pakistan

and

College of Life Science,
Linyi University, Linyi
Shandong, China

Adeeb Fatima
Laboratory of Air Pollution and Global Climate Change
Department of Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Nadia Fatnassi
Institute of Sciences of Food Productions
National Research Council (ISPA-CNR)
Lecce, Italy

Kaouthar Feki
Biotechnology and Plant Improvement Laboratory
Center of Biotechnology of Sfax
University of Sfax
Sfax, Tunisia

Dipak Gayen
National Institute of Plant Genome Research
Jawaharlal Nehru University Campus
New Delhi, India

Annesha Ghosh
Laboratory of Air Pollution and Global Climate Change
Department of Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Alvina Gul
Atta-ur-Rahman School of Applied Biosciences (ASAB)
National University of Sciences and Technology (NUST)
Islamabad, Pakistan

Dipinte Gupta
Plant Biotechnology Lab
Department of Botany
Faculty of Science
Dayalbagh Educational Institute (Deemed University)
Dayalbagh, India

Noman Habib
Department of Botany
Government College University Faisalabad
Faisalabad, Pakistan

Muhammad Zulqurnain Haider
Department of Botany
Government College University Faisalabad
Faisalabad, Pakistan

Abdul Hamid
Laboratory of Air Pollution and Global Climate Change
Department of Botany
Institute of Science
Banaras Hindu University
Varanasi, India

John T. Hancock
Center for Research in Biosciences
University of the West of England (UWE)
Bristol, UK

Md. Mahmudul Hassan
Department of Genetics and Plant Breeding
Patuakhali Science and Technology University
Patuakhali, Bangladesh

Saeid Hazrati
Department of Agronomy and Medicinal Plants Production
Faculty of Agriculture
Azarbaijan Shahid Madani University
Tabriz, Iran

Abdullah Ijaz Hussain
Department of Chemistry
Government College University Faisalabad
Faisalabad, Pakistan

Syed Makhdoom Hussain
Department of Zoology
Government College University Faisalabad
Faisalabad, Pakistan

Noshin Ilyas
Department of Botany
PMAS Arid Agriculture University
Rawalpindi, Pakistan

Naeem Iqbal
Department of Botany
Government College University Faisalabad
Faisalabad, Pakistan

M. Tofazzal Islam
Davis College of Agriculture, Natural Resources and Design
West Virginia University
Morgantown, West Virginia

and

Department of Biotechnology
Bangabandhu Sheikh Mujibur Rahman Agricultural University
Gazipur, Bangladesh

Muhammad Jamil
Department of Botany
University of Sargodha
Sargodha, Pakistan

Muhammad Jamil
Department of Biotechnology & Genetic Engineering
Kohat University of Science and Technology
Kohat, Pakistan

Sami Ullah Jan
Department of Plant Biochemistry and Molecular Biology School of Life Sciences
University of Science and Technology of China
Hefei, People's Republic of China

Sumit Jangra
Department of Molecular Biology, Biotechnology and Bioinformatics
CCS Haryana Agricultural University
Hisar, India

Mohsen Janmohammadi
Department of Plant Production and Genetics
Faculty of Agriculture
University of Maragheh
Maragheh, Iran

Muhammad Tariq Javed
Department of Botany
Government College University Faisalabad
Faisalabad, Pakistan

Ambuj Bhushan Jha
Crop Development Center Department of Plant Sciences
University of Saskatchewan
Saskatoon, Saskatchewan Canada

Disha Kamboj
Department of Molecular Biology, Biotechnology and Bioinformatics
CCS Haryana Agricultural University
Hisar, India

Vigya Kesari
Molecular Biology Section, Laboratory of Algal Biology
Center of Advanced Study in Botany
Institute of Science,Banaras Hindu University
Varanasi, India

Daeha Kim
Climate Analytics Team, Climate Services and Research Department
APEC Climate Center
Busan, Republic of Korea

Nicholas E. Korres
Department of Crop, Soil, and Environmental Sciences
University of Arkansas
Fayetteville, Arkansas

Nilesh Vikram Lande
National Institute of Plant Genome Research
Jawaharlal Nehru University Campus
New Delhi, India

Eun-Jeong Lee
Climate Analytics Team, Climate Services and Research Department
APEC Climate Center
Busan, Republic of Korea

Wooseop Lee
Climate Analytics Team, Climate Services and Research Department
APEC Climate Center
Busan, Republic of Korea

Sanai Li
Climate Analytics Team, Climate Services and Research Department
APEC Climate Center
Busan, Republic of Korea

Eduardo C. Machado
Laboratory of Plant Physiology "Coaracy M. Franco"
Center for R&D in Ecophysiology and Biophysics
Agronomic Institute (IAC)
Campinas, Brazil

Deyvid Novaes Marques
Instituto de Ciências Biológicas
Universidade Federal do Pará
Belém, Brazil

Roomina Mazhar
Department of Botany
PMAS Arid Agriculture University
Rawalpindi, Pakistan

Aakash Mishra
Department of Plant Sciences
University of California
Davis, California

Sushma Mishra
Plant Biotechnology Lab
Department of Botany
Faculty of Science
Dayalbagh Educational Institute (Deemed University)
Dayalbagh, India

Hamid Mohammadi
Department of Agronomy and Medicinal Plants Production
Faculty of Agriculture
Azarbaijan Shahid Madani University
Tabriz, Iran

Kutubuddin Molla
Pennsylvania State University
University Park, Pennsylvania

and

National Rice Research Institute
Cuttack, India

Joseph Msanne
New Mexico Consortium
Los Alamos, New Mexico

A. Mujeeb-Kazi
Texas A&M University
College Station, Texas

Durgesh Nandini
Department of Biotechnology
Shri A. N. Patel Postgraduate Institute
Gujarat, India

Abdul Aziz Napa
Department of Plant Science
Quaid-i-Azam University
Islamabad, Pakistan

Zahra Noreen
Department of Botany
University of Education
Lahore, Pakistan

Lymperopoulos Panagiotis
New Mexico Consortium
Los Alamos, New Mexico

Ashutosh K. Pandey
Laboratory of Air Pollution and
Global Climate Change
Department of Botany
Institute of Science
Banaras Hindu University
Varanasi, India

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

Amit Kumar Patel
Molecular Biology Section
Laboratory of Algal Biology
Center of Advanced Study in Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Ashish Patel
Department of Life Sciences
Hemchandracharya North
Gujarat University
Gujarat, India

Palmiro Poltronieri
Institute of Sciences of Food Productions
National Research Council (ISPA-CNR)
Lecce, Italy

Priti
Department of Molecular Biology
Biotechnology and Bioinformatics
CCS Haryana Agricultural University
Hisar, India

Roel C. Rabara
New Mexico Consortium
Los Alamos, New Mexico

Mahfuzur Rahman
Davis College of Agriculture
Natural Resources and Design
West Virginia University
Morgantown, West Virginia

Amit Kumar Rai
Center for Genetic Disorders
Banaras Hindu University
Varanasi, India

Kshama Rai
Laboratory of Air Pollution and Global Climate Change
Department of Botany
Institute of Science
Banaras Hindu University
Varanasi, India

L.C. Rai
Molecular Biology Section
Laboratory of Algal Biology
Center of Advanced Study in Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Richa Rai
Department of Botany
Banaras Hindu University
Varanasi, India

Ruchi Rai
Molecular Biology Section
Laboratory of Algal Biology
Center of Advanced Study in Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Shweta Rai
Molecular Biology Section
Laboratory of Algal Biology
Center of Advanced Study in Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Rajiv Ranjan
Plant Biotechnology Lab
Department of Botany
Dayalbagh Educational Institute
(Deemed University)
Dayalbagh, India

Sávio Pinho dos Reis
Instituto de Ciências Biológicas
Universidade Federal do Pará
Belém, Brazil

and

Centro de Ciências Biológicas e da Saúde
Universidade do Estado do Pará
Marabá, Brazil

Rafael V. Ribeiro
Laboratory of Plant Physiology "Coaracy M. Franco"
Center for R&D in Ecophysiology and Biophysics
Agronomic Institute (IAC)
Campinas, Brazil

and

Laboratory of Crop Physiology
Department of Plant Biology
Institute of Biology
University of Campinas (UNICAMP)
Campinas, Brazil

Maimona Saeed
Department of Botany
PMAS Arid Agriculture University
Rawalpindi, Pakistan

Walid Saibi
Biotechnology and Plant Improvement Laboratory
Center of Biotechnology of Sfax
University of Sfax
Sfax, Tunisia

Angelo Santino
Institute of Sciences of Food Productions
National Research Council (ISPA-CNR)
Lecce, Italy

Shah Saud
College of Horticulture
Northeast Agricultural University Harbin
Heilongjiang, China

Amedea B. Seabra
Center for Natural and Human Sciences Federal University of ABC
Santo André, Brazil

Sumreena Shahid
Department of Botany
Government College University Faisalabad
Faisalabad, Pakistan

Neidiquele M. Silveira
Laboratory of Plant Physiology "Coaracy M. Franco"
Center R&D in Ecophysiology and Biophysics
Agronomic Institute (IAC)
Campinas, Brazil

Babar Shahzad
School of Land and Food
University of Tasmania
Hobart, Australia

Alka Shankar
Molecular Biology Section
Laboratory of Algal Biology
Center of Advanced Study in Botany Institute of Science
Banaras Hindu University
Varanasi, India

Kiran K. Sharma
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Telangana, India

Pallavi Sharma
Center for Life Sciences
Central University of Jharkhand
Brambe, Ranchi, Jharkhand, India

Shilpi Singh
Molecular Biology Section
Laboratory of Algal Biology
Center of Advanced Study in Botany
Institute of Science
Banaras Hindu University
Varanasi, India

Suruchi Singh
Laboratory of Air Pollution and Global Climate Change
Department of Botany
Banaras Hindu University
Varanasi, India

Cláudia Regina Batista de Souza
Instituto de Ciências Biológicas
Universidade Federal do Pará
Belém, Brazil

Ágnes Szepesi
Department of Plant Biology
Institute of Biology
University of Szeged
Szeged, Hungary

Mohsin Tanveer
School of Land and Food
University of Tasmania
Hobart, Australia

Liliane de Souza Conceição Tavares
Instituto de Ciências Biológicas
Universidade Federal do Pará
Belém, Brazil

Aruna V. Varanasi
Department of Horticulture
University of Arkansas
Fayetteville, Arkansas

Vijay K. Varanasi
Department of Crop, Soil, and Environmental Sciences
University of Arkansas
Fayetteville, Arkansas

Neelam R. Yadav
Department of Molecular Biology
Biotechnology and Bioinformatics
CCS Haryana Agricultural
University
Hisar, India

Ram C. Yadav
Center for Plant Biotechnology
CCS Haryana Agricultural
University
Hisar, India

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