Advances In Plant Physiology

Developments and Mechanisms Underlying Plant Resilience to Changing Environment

A. Hemanttarajan

SCIENTIFIC PUBLISHERS
ADVANCES IN PLANT PHYSIOLOGY, VOLUME 18, 2019
An International Treatise Series

EDITORIAL COMMITTEE

Editor-in-Chief
A. HEMANTARANJAN
Professor of Plant Physiology
Department of Plant Physiology, Institute of Agricultural Sciences
Banaras Hindu University, Varanasi (India)
E-mail: hemantaranjan@gmail.com

INTERNATIONAL CO-ORDINATORS AND CONSULTING EDITORS

| Dr. Fabio M. Da Matta Brazil | Dr. Jaume Flexas Spain |
| Dr. Francois Widmer Switzerland | Dr. Sergey Shabala Australia |
| Dr. Uwe Druege Germany | Dr. Katya Georgieva Bulgaria |
| Dr. E. J. Baran, Argentina | Dr. Patricia León México |
| Dr. El Houssine Zaid Morocco | Dr. Hideaki Matsumoto Japan |
| Dr. Uwe Hacke U.S.A. | Dr. Estela M. Valle Argentina |
| Dr. Dominique Van Der Straeten Belgium | Dr. Heping Yang U.S.A. |
| | Dr. Eugenio Giachetti Italy |

NATIONAL CO-ORDINATORS AND CONSULTING EDITORS

| Dr. A. Vaishampayan, B.H.U., Varanasi | Dr. H. Vijayaraghavan, T.N.A.U., Coimbatore |
| Dr. P.K. Nagar, I.H.B.T., Palampur | Dr. Veena Agrawal, D.U., New Delhi |
| Dr. R. S. Dubey, B.H.U., Varanasi | Dr. Neera Garg, P.U., Chandigarh |
| Dr. P. S. Deshmukh, I.A.R.I., New Delhi | Dr. Padmanab Dwivedi, B.H.U., Varanasi |
| Dr. J.D.S. Panwar, I.A.R.I., New Delhi | Dr. A. K. Srivastava, N.R.C.C., Nagpur |
| Dr. V.P. Singh, I.A.R.I., New Delhi | Dr. Kavita Shah, B.H.U., Varanasi |
| Dr. K. P. Singh, H.P.A.U., Palampur | Dr. R. P. Sinha, B.H.U., Varanasi |
| Dr. G.S.R. Murti, I.I.H.R., Bangalore | Dr. Nalini Pandey, L.U., Lucknow |

Executive Editor
Dr. ANJALI BHARTI
R-25, Hyderabad Colony, Banaras Hindu University, Varanasi (India)
Preface

The reinforcement of Volume 18 of the Advances in Plant Physiology Series has been entirely due to commendable contributions by Scientists of Eminence in explicit fields. The enterprise of publishing the International Treatise Series on Plant Physiology has to genuinely sort out the scantiness of consequential researches, which are sincerely required for rising productivity, prosperity and sustainability of agriculture through prominently emerging technologies for reformation in metabolic boundaries necessitates mainly for abiotic stress factors. Unquestionably, our thought is to be familiar with ground-breaking science of value across the broad punitive range of the treatise. The aspiration is to make stronger the vital outcome of conscientious research in some of the very responsive areas of Plant Physiology-Plant Molecular Physiology/Biology that broadly focus upon the advancements coupled with underlying mechanisms of plant tolerance under changing environments. I remain fervent to utilize excellent new ideas to ensure the treatise made for the best research outcome done in plant sciences, in general, and plant physiology, in particular. The Volume 18, with innovative applied research, brings jointly much needed nineteen review articles by over fifty committed contributors for this volume. The Volume 18 exclusively deals with challenges of continuing worldwide concern over the stress physiology research. Conversely, this volume also highlights trace elements; plant functional research; physiological basis of yield variation; medicinal and aromatic plants.

The Volume 18 has been broadly subdivided into six applicable sections that precisely begins with substantial pieces of information on Recent Developments in Abiotic Stress Research followed by Trace Elements in Plant Function & Stress Tolerance in plant physiology; Plant Physiology: Mechanism, Tools & Regulation; Photobiology – In Agri-Horticultural Production; Tree Physiology – Physiological Disorder; Biomass Resources, Bioenergy Potential and Environmental Protection and so on. The Section I consists of 9 Chapters focusing upon the abiotic stresses, physiological and molecular strategies for mitigation and crop productivity. The Chapter 1 focuses upon EPR based free radical detection in plants. Subsequently, in second chapter, an enthusiastic team of scientists portray ROS to be a multifaceted moiety that impacts at cellular level. Therefore, with the aim to develop strategies for stress mitigation and management has been detailed including long term changed redox in favour of more oxidation to reduction. Next to this, in Chapter 3, a vibrant team of scientists have justified that osmoprotectants mainly stabilize proteins and assist to reduce osmotic potential in membranes for preventing dehydration inside the cell. Hence, emphasize prudently the essentiality of non-reducing sugars for combating plant abiotic stresses. In Chapter 4, focus has been given by devoted workers of University of Kashmir, Srinagar on salicylic acid (SA) and its role as mitigating agent for both abiotic and biotic stress. Authors consolidate considerable progress made in recent years. The Chapter 5, 6 and 7 extensively reveal impacts of high temperature extremes, heat stress management and heat tolerance mechanism, on the one hand, and the serious issue of terminal heat stress, which is a major problem in India on wheat production, on the other hand. Authors explain physiological adaptations and dynamics
for plant productivity under heat stress tolerance. Nevertheless, in Chapter 8 authors have substantially focused on physiological mechanisms and management of another major concern of salinity stress. Next to this in Chapter 9, the industrious team of BHU has creditably identified brassinosteroids, a plant growth regulator, as the modern weapon in agriculture against abiotic stresses and has highlighted several work help mitigating the problem of stresses.

In Section II, there are three substantial review articles on Trace Elements In Plant Function & Stress Tolerance in plant physiology, which explains the significance of lithium in plants in Chapter 10 by the dedicated scientist from Argentina; detailed account on the physiology and biochemistry of plant iron nutrition in Chapter 11 and above all the beneficial role of silicon on growth, metabolism and stress tolerance mechanisms in rice plants that is a vital aspect in case of rice crop.

Certainly, Volume 18 is strengthened with four major topics of the Section III especially classified for reviews focusing upon Mechanism, Tool and Regulation in the Broader Areas of Plant Physiology. The Chapter 13 scientifically draws attention to chlorophyll fluorescence, which are physiological mechanisms and physical tool in plant eco-physiological studies and has been well written by five Indian authors of eminence. Similarly Chapter 14 emphasizes over an effective tool for conservation of endangered and valuable medicinal plants through seed invigoration techniques. The whole review article has been presented with relevant photo plates and adequate descriptions. Another physiological aspect chosen in Chapter 15 is to specify upon pertinent master regulators in physiology of plants and how the master regulators of the group of brassinosteroids could be of significance in certain regulatory mechanisms of plants have been endeavoured to be underscored in this chapter. All the same, an extremely needed Chapter 16 has been brought with recent knowledge on secondary metabolites having vast impact on plant functions. Brilliant authors have no doubt taken enormous pains in organizing the chapter comprehensively.

This volume becomes novel beyond doubt by introducing Photobiology – In Agri-Horticultural Production as the Section IV, which presents a prudently well organized review article that reviews appropriate implications of solar radiation for agri-horticultural production in Chapter 17. The next segment in this series is the Section V, centered on Tree Physiology–Physiological Disorder, covers from simple to complex, focusing upon and discussing the internal breakdown in mango (Mangifera indica L.) at length, which is an important physiological disorder of the king of fruits. Eventually, the Section VI on Biomass Resources, Bioenergy Potential and Environmental Protection reflecting rightly the potential biomass for energy generation and future prospects in India in Chapter 19, which reviews potential of various biomass sources for energy generation and technologies used for their conversion. The Indian biomass energy policy, the growth in global bioenergy sector and the scope for amendments in biomass energy policy forms a notable part of this review.

In this dedicated enterprise, I am elated to state my authentic admiration to the Members of the Advisory Committee as well as to all prominent and endowed contributors from well known institutions for bringing up this unrivalled, rational, attentive and extensive treatise...
up to the international standard. In addition, I am tremendously grateful to the Fellow Members of the Indian Society for Plant Physiology, New Delhi for their honest moral support and valued suggestions from time to time. My heartfelt thankfulness is infinitely due to the Vice-Chancellor, Professor Rakesh Bhatnagar, Banaras Hindu University, the Director & formerly Dean, Professor A. Vaishampayan, Institute of Agricultural Sciences, Faculty of Agriculture, my admired and well-linked colleagues of the Banaras Hindu University as well as other universities and research institutions/centers across the globe for their steady moral support in execution of the dedicated but immense academic task.

Last but not the least, I am beholden to my family members for their blessings and good wishes in this broad mission. I have my profound admiration to all of them. Besides this, I am extremely thankful to the excellent and talented human resources of the Scientific Publishers, Jodhpur, India, for their genuine competence in the perfect printing of international standard and worldwide circulation. I am committed for the pious responsibility to my revered father Late Dr. A. Chittaranjan Sahay to continue with the International Treatise Series as far as practicable!

A. Hemantaranjan
List of Contributors

Smita Sundaram, Advanced Instrumentation Research Facility, Jawaharlal Nehru University, New Delhi, INDIA

Shweta Kaur, School of Environmental Sciences, Jawaharlal Nehru University, New Delhi-110 067, INDIA

Indu Shekhar Thakur, School of Environmental Sciences, Jawaharlal Nehru University, New Delhi-110 067, INDIA

M.K. Adak, Physiology and Molecular Biology Research Laboratory Department of Botany University of Kalyani, Kalyani 74 1235, West Bengal, INDIA

Arnab Kumar De, Physiology and Molecular Biology Research Laboratory Department of Botany University of Kalyani, Kalyani 74 1235, West Bengal, INDIA

Wasifa Hafiz Shah, Department of Bioresources, University of Kashmir, Srinagar, INDIA

Aadil Rasool, Department of Bioresources, University of Kashmir, Srinagar, INDIA

Inayatullah Tahir, Department of Botany, University of Kashmir, Srinagar, INDIA

Reiaz Ul Rehman, Department of Bioresources, University of Kashmir, Srinagar, INDIA

A. Hemantaranjan, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

A. Nishant Bhanu, Department of Genetics & Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

M. N. Singh, Department of Genetics & Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Kartikey Srivastava, Department of Genetics & Plant Breeding Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Deepmala Katiyar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Asha Kumari, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Shivani Lalotra, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Jyostanarani Pradhan, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Khushboo Gupta, Department of Plant Physiology Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA
Vivek Pratap Singh, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Rupanshee Srivastava, Department of Genetics & Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

Prachi Garg, Department of Genetics & Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221 005, INDIA

T.P. Singh, Division of Seed Science And Technology, I.A.R.I., New Delhi 110012, INDIA

Sunil Kumar, Scientist, NBSSLUP, Regional Station Udaipur, Rajasthan, INDIA

Jyoti Kumari, National Bureau Plant Genetic Resources, New Delhi 110012, INDIA

Vikender Kaur, National Bureau Plant Genetic Resources, New Delhi 110012, INDIA

P.S. Deshmukh, Ex-Head, Division of plant physiology, IARI, New Delhi 110012, INDIA

S. Nithila, Tamil Nadu Agricultural University, ADAC&RI, Tiruchirappalli, INDIA

R. Sivakumar, Tamil Nadu Agricultural University, Regional Research Station, Paiyur, INDIA

Jyostnarani Pradhan, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University- 221005, INDIA

Shivani Lalotra, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University- 221005, INDIA

Enrique J. Baran, Centro de Química Inorgánica (CEQUINOR/CONICET,UNLP) Facultad de Ciencias Exactas, Universidad Nacional de La Plata, Bvd. 120 N° 1465, 1900-La Plata, Argentina

Laxmi Verma, Plant Nutrition and Stress Physiology Laboratory, Botany Department, University of Lucknow, Lucknow 226007, INDIA

Nalini Pandey, Plant Nutrition and Stress Physiology Laboratory, Botany Department, University of Lucknow, Lucknow 226007, INDIA

Rakesh Sil Sarma, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, INDIA

Pravin Prakash, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, INDIA

K.A. Kalariya, ICAR-Directorate of Groundnut Research, P.B. 5, Junagadh 362 001, Gujarat & ICAR-Directorate of Medicinal and Aromatic Plants Research, Anand 388001, Gujarat, INDIA

Nisha Goswami, ICAR-Directorate of Groundnut Research, P.B. 5, Junagadh 362 001, Gujarat, INDIA Deepti Mehta, ICAR-Directorate of Groundnut Research, P.B. 5, Junagadh 362 001, Gujarat, INDIA

A.L. Singh, ICAR-Directorate of Groundnut Research, P.B. 5, Junagadh 362 001, Gujarat, INDIA
List of Contributors

P L. Saran, ICAR-Directorate of Medicinal and Aromatic Plants Research, Anand 388001, Gujarat, INDIA

Dhiman Mukherjee, Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani-741235, West Bengal, INDIA

Pallabi Kalita Hui, Department of Biotechnology and Chemical Engineering, National Institute of Technology Arunachal Pradesh (NIT AP), Yupia-791112, Papumpare, Arunachal Pradesh, INDIA

Hui Tag, Department of Botany, Rajiv Gandhi University, Rono Hills, Doimukh-791112, Papumpare, Arunachal Pradesh, INDIA


G. Pandey, ICAR - Central Institute for Subtropical Horticulture, Rehmankhera, P.O. – Kakori, Lucknow - 226 101, INDIA


V. K. Singh, ICAR-Central Institute for Subtropical Horticulture, Rehmankhera, Lucknow-226 101, INDIA

Lakshmi Pathak, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi-221005 (U.P), INDIA

Kavita Shah, Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi-221005 (U.P), INDIA
# Contents

<table>
<thead>
<tr>
<th>Section I: Recent Developments in Abiotic Stress Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Role of Electron Paramagnetic Resonance (EPR) Spectroscopy in Detection of Stress Generated Free Radicals in the Plant</td>
</tr>
<tr>
<td>—Smita Sundaram, Shweta Kaur, Indu Shekhar Thakur</td>
</tr>
<tr>
<td>—M.K. Adak, Arnab Kumar De</td>
</tr>
<tr>
<td>3. Non-Reducing Sugars for Combating Plant Abiotic Stresses</td>
</tr>
<tr>
<td>—Wasifa Hafiz Shah, Aadil Rasool, Inayatullah Tahir, Reiaz Ul Rehman</td>
</tr>
<tr>
<td>4. Salicylic Acid—A Mitigating Agent for Conferring Stress Tolerance in Plants</td>
</tr>
<tr>
<td>—Aadil Rasool, Wasifa Hafiz Shah, Inayatullah Tahir, Reiaz Ul Rehman</td>
</tr>
<tr>
<td>5. Physiological Effects of Temperature Extremes, Heat Stress Management and Tolerance Mechanism</td>
</tr>
<tr>
<td>6. Impact of Terminal Heat on Wheat Production in India</td>
</tr>
<tr>
<td>—T.P. Singh, Sunil Kumar, Jyoti Kumari, Vikender Kaur</td>
</tr>
<tr>
<td>—T.P. Singh, Jyoti Kumari, Sunil Kumar, Vikender Kaur, P.S. Deshmukh</td>
</tr>
<tr>
<td>—A.S. Nithila, R. Sivakumar</td>
</tr>
<tr>
<td>—J. Pradhan, A. Hemantaranjan, S. Lalotra</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section II: Trace Elements in Plant Function and Stress Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Lithium in Plants</td>
</tr>
<tr>
<td>—Enrique J. Baran</td>
</tr>
<tr>
<td>11. Iron in Plants: An overview</td>
</tr>
<tr>
<td>—Laxmi Verma and Nalini Pandey</td>
</tr>
</tbody>
</table>
12. Beneficial Role of Silicon (Si) on Growth, Metabolism and Stress Tolerance Mechanisms in Rice (*Oryza Sativa* L.) 183–200
   —Rakesh Sil Sarma and Pravin Prakash

### Section III: Plant Physiology: Mechanism, Tools and Regulation

13. Chlorophyll Fluorescence: A Physiological Mechanism and a Physical Tool in Plant Eco-physiological Studies 201–242

   —Dhiman Mukherjee

15. brassinosteroids: The Master Regulators in Physiology of Plants 273–280
   —Asha Kumari, A. Hemantaranjan

   —Pallabi Kalita Hui and Hui Tag

### Section IV: Photobiology – In Agri-Horticultural Production

17. Implications of Solar Radiation for Agri-horticultural Production 293–314

### Section V: Tree Physiology – Physiological Disorder

18. Internal Breakdown in Mango (*Mangifera Indica* L.) is an Important Physiological Disorder: An Overview 315–334
   —V. K. Singh

### Section VI: Biomass Resources, Bioenergy Potential and Environmental Protection

   —Lakshmi Pathak, Kavita Shah

Index 355–366