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Plant Adaptation to Abiotic Stress: From Signaling Pathways and Microbiomes to Molecular Mechanisms

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To my parents, Mohamed Salah and Mongia, whose selfless sacrifices, guidance, and boundless love have always paved the way for me at every stage. To my wife Najeh Ben Jamaa, whose patience, encouragement, and unwavering support have been a constant pillar of strength through all my trials and triumphs. And to my children Chahd, Lina, Maria, and Haroun, whose devotion and unwavering encouragement act as an unstoppable force that drives and sustains my determination and pushes me unstoppably to excel.

Radhouane Chaffai

Preface

Plant adaptation to abiotic stress is a complex process influenced by physiological, biochemical, and molecular responses. The impact of abiotic stressors, such as drought, salinity, heavy metals, and extreme temperatures, is exacerbated by climate change and population growth. Addressing these challenges requires an interdisciplinary approach involving plant physiology, genetics, genomics, biochemistry, and microbiology. Combining knowledge from diverse fields can lead to a deeper understanding of the mechanisms that govern plant adaptation to abiotic stress and the development of effective strategies to enhance plant resilience and productivity.

The book titled *Plant Adaptation to Abiotic Stress: From Signaling Pathways and Microbiomes to Molecular Mechanisms* offers a comprehensive exploration of the current understanding of plant adaptation to abiotic stress. It covers a wide range of topics across 18 chapters, aiming to uncover the complex mechanisms underlying stress responses and contribute to the development of more resilient crop varieties. This book is an essential resource for scholars and researchers seeking a comprehensive understanding of plant adaptation to abiotic stress.

The book provides a comprehensive analysis of plant adaptation to abiotic stress, making it an invaluable resource for professionals in the field. This includes plant scientists, agronomists, breeders, and individuals working toward sustainable agricultural practices. By addressing the urgent challenges of global food insecurity and climate change, the book provides valuable insights and perspectives that can inform the creation of effective strategies to improve plant resilience and guarantee food security in difficult environmental conditions. Its interdisciplinary approach and strong scientific foundation make it a valuable reference for both researchers and practitioners.

The Arabidopsis genome sequencing project has significantly advanced our understanding of plant responses to environmental cues, revealing intricate regulatory networks and gene expression patterns. Gene overexpression techniques have played a crucial role in understanding the functional roles of stress-related genes. Manipulating gene expression levels has allowed researchers to identify critical regulatory factors and understand their precise impact on stress tolerance.

This approach has systematically identified candidate genes in stress signaling pathways, providing insights into the upstream regulators and downstream target genes that are regulated by transcription factors. These findings have expanded our understanding of the intricate molecular mechanisms involved in plant stress

responses and provide valuable insights for genetic engineering and strategies to enhance crop improvement.

In plant research, biochemical and molecular genetic methods have been crucial for understanding gene function and regulation. Mutant analysis, in particular, has become a powerful tool for uncovering the specific roles of genes by studying the phenotypic changes that result from mutations.

The emergence of genome editing and RNA interference techniques has greatly enhanced our ability to study gene function and regulation in plants. These innovative methods have facilitated the identification and understanding of the roles of numerous genes and pathways involved in plant stress responses. The insights gained from these studies have significant potential for developing stress-resistant crop varieties and improving agricultural practices to mitigate the detrimental effects of environmental stress.

Plants employ various mechanisms to respond to environmental stress, including stress sensor-mediated signaling pathways. These pathways, which involve calcium sensors and abscisic acid, play a crucial role in controlling gene expression and influencing plant growth and development during stress. Additionally, gene regulation in plants is influenced by complex processes such as DNA methylation, histone deacetylation, transcription factors, DNA sequence variations, and miRNAs.

Understanding these molecular mechanisms is essential for improving plant performance and resilience in challenging environments. Environmental stressors can also regulate gene expression through protein function and complex protein–protein interactions, adding complexity to plant stress response networks.

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About the Authors

Radhouane Chaffai an Assistant Professor at the Higher Institute of Biotechnology of Sidi Thabet (ISBST), the University of Manouba (UMA), Tunisia, boasts over three decades of teaching experience across educational levels, from colleges and high schools to universities. His research, spanning approximately 30 years, focuses on plant physiology, particularly examining plant responses to heavy metals such as aluminum, cadmium, copper, and zinc. Dr. Chaffai has mentored and co-supervised numerous students in their final-year projects, master's, and PhD theses. His academic journey began with a Diplôme d'Études Approfondies (DEA) at the University of Tunis El Manar in 1997, culminating in a PhD in Biology from the University of Carthage, Tunisia, in 2003. In 2008, he earned the prestigious JSPS Postdoctoral Fellowship for Foreign Researchers, engaging in collaborative research with Professor Hiroyuki Koyama at Gifu University's Plant Cell Technology Laboratory from 2009 to 2011. Dr. Chaffai has an extensive publication record in international peer-reviewed journals and actively presents at national and international conferences. His consistent involvement in these academic forums underscores his notable scholarly contributions and efforts in fostering successful research collaborations among his peers.

Markkandan Ganesan is an Assistant Professor in the Department of Life Sciences at Presidency University, Kolkata, India. Concurrently, he serves as the coordinator at the School of Biotechnology within Presidency University. Possessing extensive expertise in various plant biology and plant molecular biological techniques, including photobiotechnology and biofuels, Dr. Ganesan obtained his PhD from Bharathidasan University in Tiruchirappalli, India. Subsequently, he conducted postdoctoral research at Jeju National University in South

Korea. He was selected through an open recruitment for the JSPS Postdoctoral Fellowship Program for Foreign Researchers at Gifu University in Japan. At Presidency University, he leads a research group dedicated to advancing the development of transgenic turfgrass. Additionally, his investigations have focused on the effects of abiotic stress, particularly heavy metal and acid soil stress, on plant root development. Dr. Ganesan has an extensive publication record, with over 30 research and review papers published in peer-reviewed international journals and books. Moreover, he has actively presented his research findings in numerous international and national-level conferences and meetings. Dr. Ganesan's remarkable contributions to the field of biotechnology have earned him numerous prestigious awards and honors, underscoring the significance of his scholarly endeavors.

Ameur Cherif holds the position of Microbiology Professor at the Higher Institute of Biotechnology of Sidi Thabet (ISBST) and heads the LR Biotechnology and Bio-Geo Resources Valorization (LR11ES31). Presently, he serves as the Vice-President of Scientific Research at Manouba University (UMA), Tunisia. Dr. Cherif's academic journey commenced with a bachelor's degree in natural sciences in 1995, followed by a master's degree in genetics and molecular biology in 1997. Subsequently, he earned his doctoral degree in microbiology in 2001. He directed the ISBST from 2010 to 2014. Specializing in molecular microbial ecology and biotechnology, his expertise focuses on microbial-mediated degradation and detoxification of pollutants in contaminated environments. Dr. Cherif's research delves into the phylogeny and ecology of extremophilic microbes, symbionts, commensals, and pathogen microbiota across various hosts. He concentrates on plant growth-promoting rhizobia and the biotechnological applications of active biomolecules. His prolific research has garnered recognition through publications in esteemed international peer-reviewed journals. Additionally, he actively engaged in the European Cost Action FA 0701, partnered in various EU FP7, Tempus, Erasmus, H2020 projects and holds significant roles on various review and editorial committees. Prof. Cherif boasts an impressive publication record of over 80 peer-reviewed articles and book chapters.

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