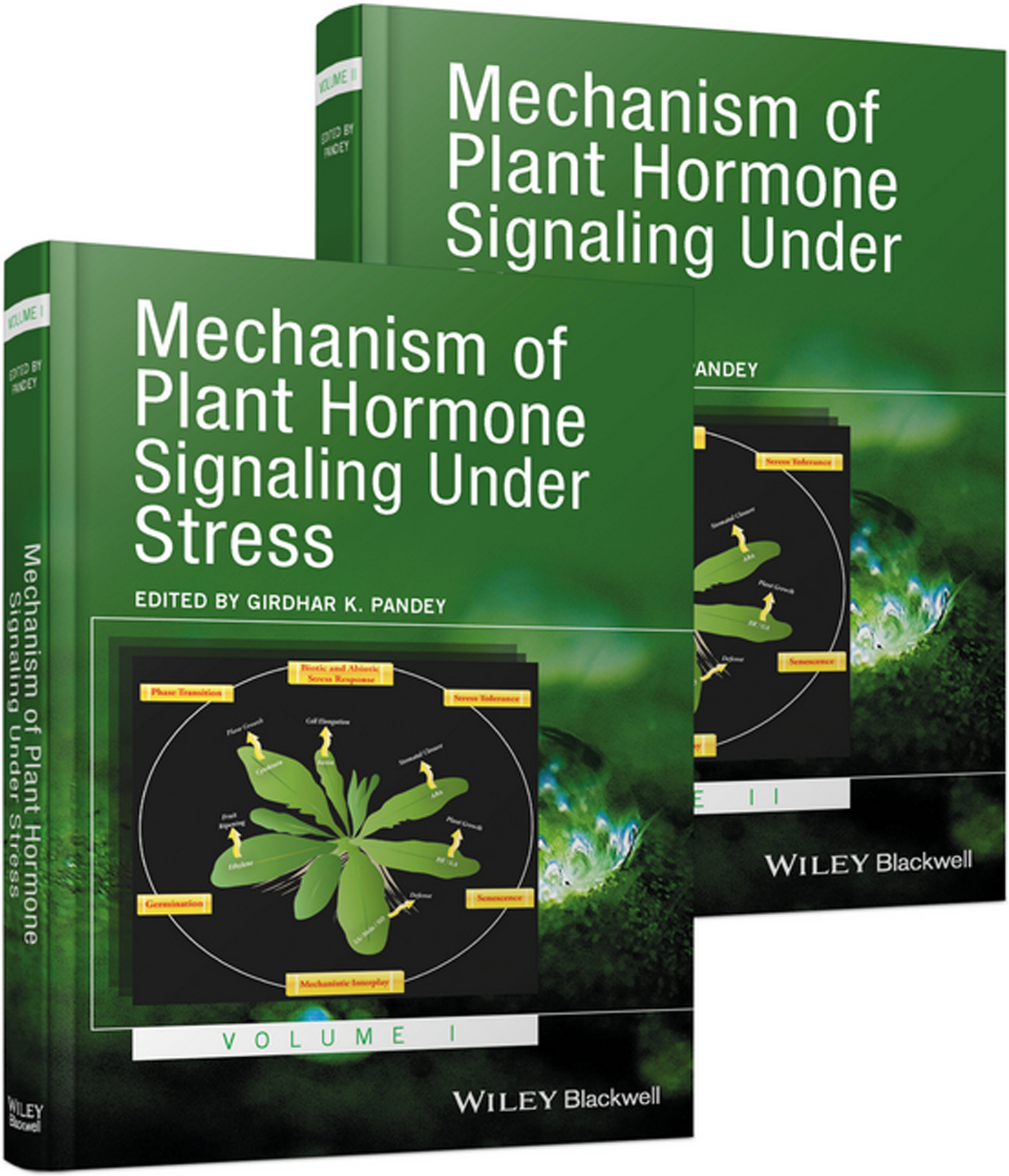

Mechanism of Plant Hormone Signaling Under Stress

EDITED BY GIRDHAR K. PANDEY

VOLUME I

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Mechanism of Plant Hormone Signaling under Stress

Cover Image Description

The image presents a holistic view of the functional role of phytohormones. Different classes of plant hormones perform a myriad of functions starting from germination, vegetative, to reproductive phase transition; abiotic and biotic stress responses, defense against pathogens, and senescence. Plant hormones are known to regulate and interact with other hormones and more than one hormone is frequently involved in different signaling pathways, suggesting a mechanistic interplay among them in regulating plant growth, development, and physiological responses.

Mechanism of Plant Hormone Signaling under Stress

Edited by Girdhar K. Pandey
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Volume I

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Contents

Part I Action of Phytohormones in Stress *1*

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Girdhar K. Pandey received his B.Sc. (Hon.) in Biochemistry from Delhi University in 1992 and M.Sc. in Biotechnology in year 1994 from Banaras Hindu University (BHU). Subsequently, he joined the School of Life Sciences for his Ph.D., Jawaharlal Nehru University (JNU), and worked in the field of calcium signal transduction under abiotic stresses in plants. He was awarded the Ph.D. degree in 1999 and then pursued a post-doctoral career at the Department of Plant and Microbial Biology, University of California, Berkeley in 2000. There, he extended his work in the field of calcium-mediated signaling in *Arabidopsis* by studying CBL-CIPKs, phosphatases, channels/transporters, and transcription factors involved in abiotic stresses. Currently, he is working as Professor in the Department of Plant Molecular Biology, Delhi University South Campus.

Pandey's research interests involve detail mechanistic interplay of signal transduction networks in plant under mineral nutrient deficiency (mostly potassium, calcium, and nitrate) and abiotic stresses such as drought, salinity, and oxidative stresses induced by heavy metals. His laboratory is working on the coding and decoding of mineral nutrient deficiency and abiotic stress signals by studying several signaling components such as phospholipases (PLA, PLC, and PLD), calcium sensors such as calcineurin B-like (CBL) and CBL-interacting protein kinases (CIPK), phosphatases (mainly PP2C and DSP), transcription factors (AP2-domain containing or ERF, WRKY), transporters and channels proteins (potassium and calcium channels/transporters), small GTPases, and Armadillo domain containing proteins in both *Arabidopsis* and rice. The long-term goal of his research group is to establish the mechanistic interplay and crosstalk of mineral nutrient deficient conditions and different abiotic stress signaling cascades in *Arabidopsis* and rice model systems by using the advance tools of bio-informatics, genetics, cell biology, biochemistry, and physiology with greater emphasis on functional genomics approaches.

See Pandey's web page for further information about his lab and research work: https://sites.google.com/site/gkplab/home; www.dpmb.ac.in/index.php?page=girdhar-pandey

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Preface

One of the basic biological differences between plants and animals is in their habit of growth and development. During the processes of evolution, unlike animals, plants adopted sessile and relatively immobile growth habits to complete their lifecycle. However, common key chemical communicators called "hormones" regulate growth and development in a similar fashion in plants and animals. Plant hormones are known as "phytohormones," which act locally and systemically to regulate their growth and development. The importance of phytohormones in a plant's biological activities can be perceived well typically in a tissue culture system, where a slight alteration in the level of various hormones lead to development of undifferentiated mass of cells called the *callus*.

The Phytohormones act at a very low concentration, usually in nano- to micro molar amounts within a plant cell. Owing to this, initial attempts to understand the biochemical and functional role of phytohormones remained inconclusive. However, with the help of chemical synthesis, large-scale purification, and through mutant based genetic approaches, valuable information to understand the underlying mechanism has been unearthed for the role of phytohormones over the past few decades. The detailed biosynthetic and signal transduction pathways have been identified for most of the classical phytohormones like auxin, abscisic acid, gibberllin, cytokinin, and ethylene along with the newly discovered brassinosteroids, salicylic acid, jasmonic acid, nitric oxide, and others. Using the tools of genetics, biochemistry, and molecular biology, plant biologists are now able to develop a concrete roadmap starting from the biosynthesis to perception and action of many of these phytohormones in regulating physiological and developmental responses.

Mounting evidence suggest that, besides regulating the growth of plants, phytohormones are the critical factors that also play a role in fine-tuning the metabolism and physiology of the plants under varying environmental cues. In the natural growth environment, plants perceive a large number of favorable (nutrient, water, light) and unfavorable stimuli (abiotic and biotic stresses), which influence their growth and development. To counteract these adverse conditions, plants have developed an intricate web of complex machineries to translate perceived stress signal into effective response by modulating the gene expression or directly affecting the physiology of the cell. Phytohormones or plant growth regulators are the key chemical molecules that are involved in broad spectrum of signaling pathways in response to a particular abiotic or biotic stress mounting an effective defense response.

Similar to other signaling molecules, phytohormones act coordinately to generate synergistic, antagonistic, and additive or subtractive responses. The direct indication of this cross talk is considered to be based on molecular interactions between factors regulating phytohormone signal action pathways. Thus, to elucidate the molecular mechanism of possible integration of phytohormone signaling pathways with the intermediates of other signaling cascades under a given condition requires the major attention of plant biologists.

More than ever, in the current state where aggressive climate change, rapidly growing population, and diminishing fertile land due to increased exploitation of natural resources imposes serious threat to crop production worldwide. And so, the major focus of plant biologists across the world is to improve crop productivity and yield. With the development of gene cloning, genetic engineering, and genome editing, modification of a food crop's genetic makeup to accustom it toward changing conditions paves way for the possibility of development and enhancement of tolerance against these stresses. In the field conditions, crops are constantly exposed to multitude of stresses and efforts are being focused towards generating new crop varieties that can tolerate these multiple stresses without yield loss. Detail molecular understanding of the cross talk and interaction of different phytohormones would certainly open new directions to design strategies to generate stress tolerant high yielding crop varieties.

In the post-genomic era, one of the major challenges is the functional analysis and understanding of plant hormone associated multiple genes and gene families regulating a particular physiological and developmental aspect of plant lifecycles. One of the important physiological processes is stress response regulation, which leads to adaptation in response to adverse stimuli. With the holistic understanding of the molecular mechanism of plant hormones associated signaling involving more than one gene family, plant biologist can lay the foundation for designing and generating future crops, which can withstand adverse environmental conditions without compromising on yield and productivity.

This book on *Mechanism of Plant Hormone Signaling under Stress* comprises of two volumes (Volume I and Volume II with 18 chapters in each). Several plant biologists throughout the world have contributed in the field of 'mechanisms of plant hormone action' in plants with a special emphasis on 'stress signaling in plants'. This book describes the timely and state-of-art contribution to knowledge in the field of 'phytohormone mediated signaling under stress' to develop a better and holistic understanding of hormone stress perception, transduction followed by the generation of response.

Despite of availability of large number of publications in the field of action of phytohormones during stress conditions, the in-depth analysis of this aspect has not been covered in previous books and volumes. Above all, the topics include a greater emphasis on genomics and functional genomics aspects in order to understand the global and whole genome level changes under particular stress conditions through a functional genomics perspective.

With functional genomics tools, the mechanisms of phytohormone signaling and their target genes can be defined in a more systematic manner. The integrated analysis of phytohormone signaling under single or multiple stress conditions may prove exceptional to design stress tolerant crop plants in field conditions. Toward achieving this goal, the book is divided into four sections. Volume I comprises the first part where 18 chapters on *Action of Phytohormones in Stress* discusses the mechanistic action of the most common phytohormones, and their roles in stress signaling in plants. These chapters will aware the readers primarily on the detailed signaling pathways and their roles in various stress conditions in plants. The first three chapters (Chapter 1–3) are dealing with the various aspects of biosynthesis, signaling, and action of classical phytohormone, auxin in multiple stress conditions. The Chapter 4 describes the metabolism, homeostasis, and signaling pathways of another classical phytohormone, cytokinin, known to regulate growth and differentiation in plants, also involved in various stress conditions. GA also belongs to the category of classical phytohormone regulating plant growth by cell division and elongation. Chapter 5 and 6 discuss the various roles of GA, its metabolism, signal transduction pathways, and also its interaction with JA in stress conditions in plants. In continuation with Chapter 6, where interaction of GA with JA is discussed, their elaborate role, metabolism, and signaling pathway is discussed in detail in Chapter 7 with a special emphasis of JA in stress management. The another typical phytohormone, ABA, long known to regulate stress related responses in plants is extensively discussed in Chapters 8–11, where different contributors have discussed its in-depth signal transduction and mechanism of action in regulating both abiotic and biotic stresses. Ethylene is also a conventional gaseous hormone known to regulate fruit ripening and senescence in plants. Chapters 12 and 13 discusses the elaborate aspects of ethylene signal transduction and responses under both abiotic and biotic stresses and cross talk with other phytohormones. Chapters 14 to 16 emphasizes the signal transduction and detail role of another gaseous hormone, nitric oxide or NO and the process of S-nitrosylation in several abiotic stress conditions in plants. Salicylic acid (SA) is mostly appreciated as an important phytohormone regulating biotic stress. SA is also well elaborated upon in multiple abiotic stresses in Chapter 17. The last chapter of the Part I (Chapter 18) describes the complex interplay of brassinosteroid (BR) and glucose in growth and development, and also during environmental stress conditions.

Volume II of this book contains three parts (Parts II–IV) consisting of 18 chapters in total. Part II of this book describes the role of several different factors that are intangibly linked with phytohormone signaling under biotic and abiotic stresses. Chapters 1 and 2 elaborate the role of reactive oxygen species (ROS) in regulating both abiotic and biotic stress responses. ROS are key signaling molecules, which are also interacting and participating in multiple phytohormone-mediated signaling and response pathways during various stress conditions in plants. Calcium (Ca^{2+}) is a metal ion involved in regulating a plethora of biological processes including stress signal transduction pathways in plants. Ca^{2+} acts as second messenger and is involved in signaling pathways of several phytohormones. The most studied phytohormone where Ca^{2+} is a pivotal signaling molecule is abscisic acid (ABA) regulating several abiotic stress responses. Chapter 3 focuses on the role of Ca^{2+} signaling components and their complex interplay with multiple phytohormones in plants. Chapter 4 reports the role of phospholipids in regulating various signaling pathways during biotic and abiotic stresses and their interaction with phytohormones. Emerging evidences showing effects of biotic and abiotic stresses on cytoskeletal protein network mediated through different phytohormone is highlighted in Chapter 5. In the Chapter 6, the role of several proteins involved in metabolism, transport, and signal transduction of different phytohormones is discussed. Further, increased use of man-made chemicals such as organic compounds mainly used as pesticides, herbicides, and fungicides has resulted in the accumulation of these xenobiotic compounds in the environment that leads to interference with plant hormone signaling and metabolism. Chapter 7 articulates important aspects of interaction of xenobiotic compounds with phytohormone signaling and metabolism, and opens up new possibilities to investigate these aspects at molecular levels. In Chapter 8, the role of phytohormone mediated signaling in several metal stresses and how plants changes their growth and development in response to toxic metal ions is well documented.

Part III (in Volume II) of this book comprised of three chapters, which mainly discusses the role of transcription factors, transcription activators, and microRNA in the regulation of phytohormones related gene expression under stress and developmental conditions. In Chapter 9, the development of stomata by several transcription factors and their regulation by multiple phytohormones is described. Since stomata is the gate-keeper that controls the passage of gases like CO_2, O_2, and are responsible for the transpirational pull of water and nutrients from the soil, their opening and closure is thoroughly fine-tuned by several phytohormones, majorly by ABA. This chapter details the interplay of phytohormones in the development of stomata and their regulation under abiotic stresses mediated by multiple phytohormones. Chapter 10 describes the role of the phytohormone regulated mediator complex. This is a large multimeric transcriptional activator complex, involved in regulating the transcription of multiple stress inducible genes. In Chapter 11, the complex regulatory roles of micro-RNA in modulating the gene expression in phytohormones and abiotic stress conditions are extensively elucidated.

The last part of this book (in Volume II), Part IV is comprised of seven chapters, mainly discussing the roles of multiple phytohormones in diverse stress adaptive responses. The first chapter in this section, i.e., Chapter 12 confers on the role of multiple phytohormones and microbial elicitors in regulating the signaling pathway in guard cell during stomatal closure. Chapter 13 elaborates on how phytohormones are involved in regulating pathogen infection and plant defense and immune response during biotic stress. In Chapter 14, the role of multiple phytohormones is described in regulating both seed development and stress responses. The important role and interaction of multiple phytohormones is once more discussed in abiotic and biotic stress responses in Chapter 15 with special emphasis on SA and its interaction with other phytohormones. With the identification of multiple phytohormones signaling pathways, it is well appreciated that many of these phytohormone shows the complex interaction because of convergence and overlap of signal transduction components such as kinases, phosphatases, transcription factors, and other signaling molecules. Chapters 16 and 17 highlight the complex interplay of several phytohormones in abiotic and biotic stress regulation and crosstalk. The last chapter of this section, Chapter 18, emphasizes on the transgenic approaches to manipulate crop productivity by altering the levels of several phytohormones. With an in-depth understanding of several signal transduction components mediated by phytohormones, the ultimate goal is to translate this mechanistic knowledge into useful tools to generate crop varieties with either genetic alteration of these signaling components, or to utilize this knowledge for molecular-marker assisted breeding, which ultimately augment stress tolerance in crop plants without compromising their productivity.

Despite my rigorous attempts, not all aspects of phytohormone signaling and components could be discussed here because of space constraints. Nevertheless, I strongly believe that this book, covering different characteristics of phytohormone signal transduction machinery with a special emphasis on the mechanistic action under stress conditions will prove extremely useful to students, teachers, and research scientists.

I am grateful to all the contributors of this work, which could not be possibly compiled without their significant contributions. At last, I would like to express my sincere thanks to Dr. M.C. Tyagi, Dr. Amita Pandey, and Ms. Manisha Sharma for critical reading and constructive suggestions related to this book. Ms. Manisha Sharma is also acknowledged for designing the cover page of this book. I am also thankful to Delhi University, University Grant Commission, Department of Biotechnology, Department of Science and Technology, and Council of Scientific and Industrial Research, India for supporting research in my laboratory.

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