The Plant Sciences

Series Editors: Mark Tester · Richard Jorgensen

Stephen H. Howell *Editor*

Molecular Biology

Springer Reference

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With 84 Figures and 10 Tables

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Editor
Stephen H. Howell
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The Plant Sciences

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The volumes in this series form the world's most comprehensive reference on the plant sciences. Composed of ten volumes, The Plant Sciences provides both background and essential information in plant biology, exploring such topics as genetics and genomics, molecular biology, biochemistry, growth and development, and ecology and the environment. Available through both print and online mediums, the online text will be continuously updated to enable the reference to remain a useful authoritative resource for decades to come.

With broad contributions from internationally well-respected scientists in the field, The Plant Sciences is an invaluable reference for upper-division undergraduates, graduate students, and practitioners looking for an entry into a particular topic.

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Preface

No area of plant sciences has had more spectacular achievements in the past 40 years than plant molecular biology. Though some may argue, the area had its genesis in 1976 with the first NATO meeting on plant molecular biology. At that time, two Harvard scientists, John Bedbrook and Lawrence Bogorad, announced that they had developed a restriction enzyme map of the *Chlamydomonas* chloroplast genome. It was a major accomplishment at the time, but since then, even more exciting breakthroughs have occurred – important plant genes have been cloned, plant transformation techniques developed, metabolic and signaling pathways identified, and whole genomes sequenced. Given the enormous scope of plant molecular biology that has developed over the years, it would be impossible to cover the area in one volume. Instead, special areas have been highlighted to give you a flavor of what has been accomplished and what lies on the horizon.

In the past few years, plant genomics has captured much of the attention in plant molecular biology; therefore, several of the chapters deal with the genome. Gutierrez et al. write in chapter "Replication of the Plant Genome" that replication of the plant genome is a huge challenge for a cell because at each division cycle, the entire genome must be fully and faithfully replicated. This is so that a new daughter cell will receive a genome copy identical to that of the parent. A major conundrum in DNA synthesis is the replication of the ends of chromosomes, called telomeres. Failure to replicate the ends of chromosomes would leave them open and result in chromosome instability. In the chapter "Plant telomeres and telomerase," Nelson et al. describe how the highly conserved telomerase enzyme seals the ends of chromosomes and they discuss how telomere replication in plants compares to animals.

Although plant genomes are faithfully replicated in each cell cycle, the integrity of the genome is always at stake because many biotic and/or abiotic perturbations can damage DNA and produce chromosome breaks or mutations. In the chapter "DNA repair and recombination in plants," Schröpfer et al. describe the many different mechanisms by which DNA lesions are repaired.

One of the most exciting areas of plant molecular biology in the past decade has been the discovery of small noncoding RNAs. Small RNAs play varied roles in gene regulation – silencing genes and serving to guide the machinery for chromatin modification to target genes. In the chapter "Small RNAs in plants," Won et al. describe the various classes of small RNAs in plants and discuss how they are synthesized and processed and function.

The bottomline for gene expression in plants is to make proteins. The translational apparatus that synthesizes proteins is an incredible molecular machine. The chapter "Plant translational machinery" by Browning describes the many factors that associate with ribosomes to promote the initiation, elongation, and termination of protein synthesis.

Plant cell organelles such as chloroplasts engage in two-way communication with the nucleus to maintain their integrity and regulate their functions. Larkin in the chapter "Chloroplast signaling in plants" describes plastid-to-nucleus communication during plant development and at times when plants accommodate to changes in photosynthesis activity. Since most chloroplast proteins are encoded by the nucleus, the nucleus communicates with plastids by activating the expression of plastid genes.

Another cytoplasmic organelle, the endoplasmic reticulum, also engages in two-way communication with the nucleus. The nucleus encodes proteins that make up the ER, and the ER in turn signals its status to the nucleus. In the chapter "ER stress signaling in plants," Howell describes a condition in which a plant is subjected to stress and the ER sends special sensors/transducers to the nucleus to activate stress response genes.

Normal growth and development and other responses to environmental conditions in plants are complex processes and rely on the operation of signaling pathways involving hormones and other cell-signaling components. The most prominent and versatile hormone in plants is auxin. As Rechenmann relates in the chapter "Auxin signaling in plants," the multitude of auxin functions is brought about by different auxins, the complexity of auxin metabolism, the gradients of the hormone generated by auxin transporters, and the combinatorial action of the large families of auxin receptors and coreceptors.

Cytokinin, the hormone best known for its action as a counterpoint to that of auxin in plant regeneration, also has pleiotrophic effects. As explained by Cheng and Kieber in the chapter "Cytokinin signaling in plants," cytokinin is unique in that the hormone uses a "two-component pathway" with a receptor transducing a signal through phosphorelay systems to nuclear-localized effectors called response regulators. Another class of hormones, the brassinosteroids, are also involved in a diversity of plant cellular functions, particularly in growth and developmental processes involving cell elongation. As Clouse points out in the chapter "Brassinosteroid signaling in plants," brassinosteroid signaling involves a membrane receptor, a signaling pathway involving protein phosphorylation, and the activation of a large number of genes.

COP9, originally discovered as a gene that negatively controls photomorphogenesis in the dark, is now recognized as part of a multifunctional complex called the COP9 signalosome. In the chapter "COP9 signalosome network," Franciosini et al. disclose how the COP9 signalosome takes part in many plant development processes and environmental responses including photomorphogenesis.

Gene regulatory networks allow plants to integrate a variety of inputs and/or generate diverse outputs. As described by Malapeira et al. in the chapter "Plant circadian network," numerous plant genes are regulated by the circuitry and feedback mechanisms of the circadian clock, which orchestrates many of the diurnal rhythms in plants. Gene networks are also involved in integrating stress information. Kuromori et al. in the chapter "Drought stress signaling network" detail how the gene network that responds to drought stress insures plant survival. Part of the drought stress gene network involves responses associated with the plant hormone abscisic acid, and part of the pathway acts independently of the hormone.

Altogether, these chapters highlight the many advances in plant molecular biology and provide a foundation for the study of other areas of plant sciences.

Ames, Iowa, USA Stephen H. Howell
May 2014

Series Preface

Plant sciences is in a particularly exciting phase, with the tools of genomics, in particular, turbo-charging advances in an unprecedented way. Furthermore, with heightened attention being paid to the need for increased production of crops for food, feed, fuel, and other needs and for this to be done both sustainably and in the face of accelerating environmental change, plant science is arguably more important and receiving more attention than ever in history. As such, the field of plant sciences is rapidly changing, and this requires new approaches for the teaching of this field and the dissemination of knowledge, particularly for students. Fortunately, there are also new technologies to facilitate this need.

In this 10-volume series, *The Plant Sciences*, we aim to develop a comprehensive online and printed reference work. This is a new type of publishing venture exploiting Wiki-like capabilities, thus creating a dynamic, exciting, cutting-edge, and living entity.

The aim of this large publishing project is to produce a comprehensive reference in plant sciences. *The Plant Sciences* will be published both in print and online; the online text can be updated to enable the reference to remain a useful authoritative resource for decades to come. The broader aim is to provide a sustainable superstructure on which can be built further volumes or even series as plant science evolves. The first edition will contain 10 volumes.

The Plant Sciences is part of SpringerReference, which contains all Springer reference works. Check out the link at http://www.springerreference.com/docs/index.html#Biomedical+and+Life+Sciences-lib1, from where you can see the volumes in this series that are already coming online.

The target audience for the initial 10 volumes is upper-division undergraduates as well as graduate students and practitioners looking for an entry on a particular topic. The aim is for *The Plant Sciences* to provide both background and essential information in plant biology. The longer-term aim is for future volumes to be built (and hyperlinked) from the initial set of volumes, particularly targeting the research frontier in specific areas.

The Plant Sciences has the important extra dynamic dimension of being continually updated. *The Plant Sciences* has a constrained Wiki-like capability, with all original authors (or their delegates) being able to modify the content.

Having satisfied an approval process, new contributors will also be registered to propose modifications to the content.

It is expected that new editions of the printed version will be published every 3–5 years. The project is proceeding volume by volume, with volumes appearing as they are completed. This also helps to keep the text fresher and the project more dynamic.

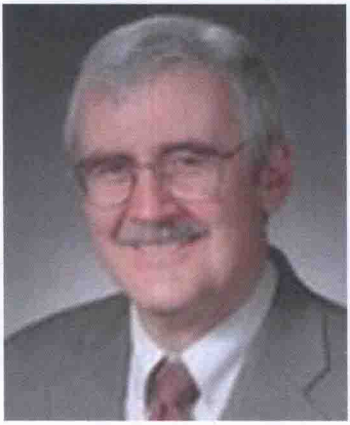
We would like to thank our host institutions, colleagues, students, and funding agencies, who have all helped us in various ways and thus facilitated the development of this series. We hope this volume is used widely and look forward to seeing it develop further in the coming years.

King Abdullah University of Science & Technology, Thuwal, Saudi Arabia — Mark Tester

School of Plant Sciences, University of Arizona, Tucson, AZ, USA — Richard Jorgensen

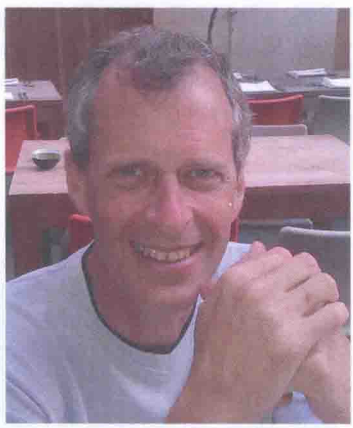
22 July 2014

Editor Biography



Stephen Howell is a Professor of Genetics, Development, and Cell Biology at Iowa State University in Ames, Iowa. He received his B.A. degree from Grinnell College in Grinnell, Iowa, and a Ph.D. degree from Johns Hopkins University in Baltimore, Maryland. He did postdoctoral work at the University of California, San Diego, and continued as a faculty member there for 20 years. He then became the Vice President for Research at the Boyce Thompson Institute at Cornell University in Ithaca, New York. Dr. Howell went to Iowa State in 2001 as Director of the Plant Sciences Institute. In 2009, he became Director of the Division of Molecular and Cellular Biosciences at the National Science Foundation. After a 2-year stint in Washington, Dr. Howell returned to Iowa State to resume his research and teaching roles. In 1980, Howell's lab was the first to introduce recombinant DNA in plants – a cloned form of the Cauliflower Mosaic Virus genome. A few years later in 1986, Howell, along with Marlene DeLuca and Donald Helinski, introduced the firefly luciferase gene into plants to produce an iconic image of a "glowing tobacco plant." In 1992, Howell organized a Gordon Conference on Plant Molecular Biology, and from 1998 to 2001, he was Editor-in-Chief of the journal *Plant Molecular Biology*. Most recently, Howell's lab has been involved in studies of ER stress in plants. The ER stress response system confers on plants the capacity to sense and respond to adverse environmental conditions – a major issue in the face of global climate change.

Series Editors Biography

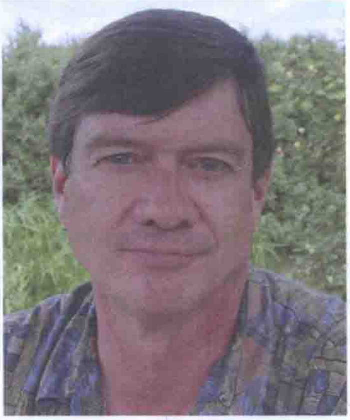


Mark Tester is Professor of Bioscience in the Center for Desert Agriculture and the Division of Biological and Environmental Sciences and Engineering, King Abdullah University for Science and Technology (KAUST), Saudi Arabia. He was previously in Adelaide, where he was a Research Professor in the Australian Centre for Plant Functional Genomics and Director of the Australian Plant Phenomics Facility. Mark led the establishment of this facility, a $55 million organisation that develops and delivers state-of-the-art phenotyping facilities, including The Plant Accelerator, an innovative plant growth and analysis facility. In Australia, he led a research group in which forward and reverse genetic approaches were used to understand salinity tolerance and how to improve this in crops such as wheat and barley. He moved to KAUST in February 2013, where this work is continuing, expanding also into work on the salinity tolerance of tomatoes.

Mark Tester has established a research program with the aim of elucidating the molecular mechanisms that enable certain plants to thrive in sub-optimal soil conditions, in particular in soils with high salinity. The ultimate applied aim is to modify crop plants in order to increase productivity on such soils, with consequent improvement of yield in both developed and developing countries. The ultimate intellectual aim is to understand the control and co-ordination of whole plant function through processes occurring at the level of single cells, particularly through processes of long-distance communication within plants.

A particular strength of Professor Tester's research programme is the integration of genetics and genomics with a breadth of physiological approaches to enable novel gene discovery. The development and use of tools for the study and manipulation of specific cell types adds a useful dimension to the research. Professor Tester received training in cell biology and physiology, specialising in work on ion transport, particularly of cations, across the plasma membrane of plant cells. His more recent focus on salinity tolerance is driven by his desire to apply his training in fundamental plant processes to a problem of practical significance.

Professor Tester was awarded a Junior Research Fellowship from Churchill College, Cambridge, in 1988, a BBSRC (UK) Research Development Fellowship in 2001, and an Australian Research Council Federation Fellowship in 2004. Professor Tester obtained his Bachelor's degree in Botany from the University of Adelaide in 1984, and his Ph.D. in Biophysics from the University of Cambridge in 1988.



Dr. Richard Jorgensen, Professor Emeritus, School of Plant Sciences, University of Arizona, Tucson, AZ, USA

Dr. Jorgensen is a recognized international leader in the fields of epigenetics, functional genomics, and computational biology. His research accomplishments include the discovery in plants of a gene-silencing phenomenon called cosuppression, which led to the discovery in animals of RNA interference, a gene-silencing tool that has major potential implications for medicine including the treatment of diseases such as cancer, hepatitis, and AIDS. In 2007, he was awarded the Martin Gibbs Medal for this groundbreaking work in cosuppression and RNAi by the American Society of Plant Biologists (ASPB). He was elected a Fellow of the American Association for the Advancement of Sciences (AAAS) in 2005 and an Inaugural Fellow of the ASPB in 2007.

Dr. Jorgensen was the founding Director of the iPlant Collaborative, a 5 years, $50 M NSF project to develop cyber-infrastructure for plant sciences. Dr. Jorgensen also served as the Editor in Chief of *The Plant Cell*, the leading research journal in plant biology, from 2003 to 2007. He is currently Editor in Chief of *Frontiers in Plant Science*, a cutting-edge, open-access journal allied with Nature Publishing Group. He is also Series Editor for the book series *Plant Genetics and Genomics: Crops and Models* for Springer Publishing. Dr. Jorgensen has published numerous scientific articles and is regularly invited to present his research findings at universities, research institutions, and scientific conferences nationally and internationally.

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