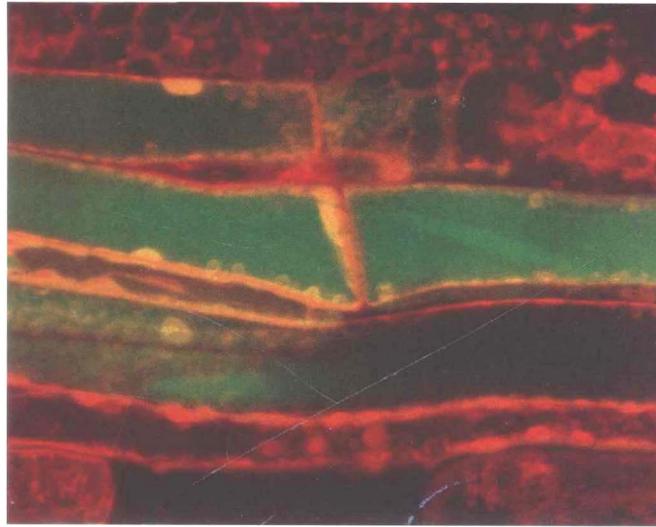


# *Plant Physiology*

**Second  
Edition**

**Taiz  
Zeiger**

# *Plant* SECOND EDITION *Physiology*



**Lincoln Taiz**

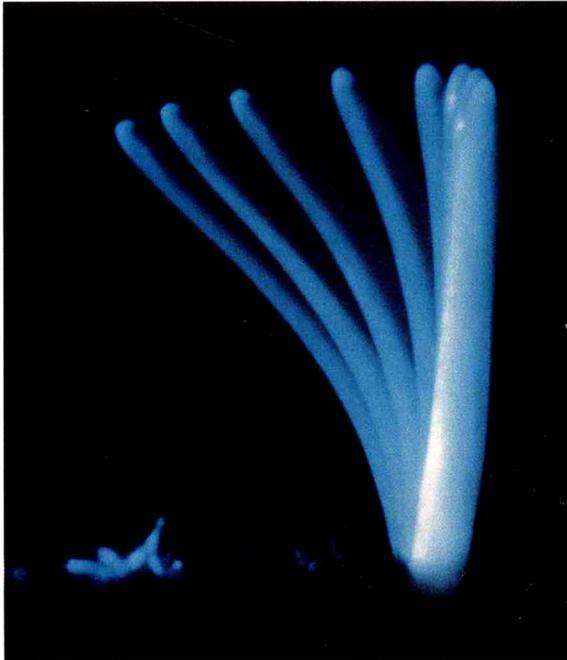
*University of California, Santa Cruz*

**Eduardo Zeiger**

*University of California, Los Angeles*



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### FRONT COVER

Mexican goldpoppies blooming beside the vascular skeleton of a cholla cactus (*Opuntia* sp.).

### BACK COVER

Close-up of the spines and flower of a strawberry hedgehog cactus. Front and back cover photographs by Willard Clay.

### THE HALF-TITLE PAGE

Localization of the sucrose-H<sup>+</sup> symporter in the phloem. This micrograph shows a single companion cell from broad-leaved plantain (*Plantago major*) stained with two fluorescent dyes. One of the dyes (green) is (indirectly) linked to an antibody that is specific for the PmSUC2 sucrose-H<sup>+</sup> symporter. The second dye (blue) binds to DNA. Since the two dyes are found on a single phloem cell, which is always adjacent to a sieve element, the sucrose symporter is concluded to be located in the companion cell membrane in this species. (From Stadler et al. 1995, courtesy of N. Sauer. See page 266 in Chapter 10.)

### THE FRONTISPIECE

TOP: Tip-growing pollen tubes exhibit a steep intracellular gradient of calcium ion concentration, with the highest levels at the growing tip. Pollen tubes from three species of plants were microinjected with a fluorescent calcium indicator dye to demonstrate this Ca<sup>2+</sup> gradient, ranging from about 1 μM at the extreme tip to about 0.2 μM at the base. (Photo from Hepler 1997, courtesy of P. Hepler. See page 436 in Chapter 15.)

BOTTOM: The nucleation and propagation of ice in the stem, buds, and leaves of rhododendron (*Rhododendron* sp.). Emission of heat (colored blue and rust) during ice formation was detected by infrared thermography. Ice nucleation was observed to begin in the stem (lower right-hand corner), and then to spread to buds and leaves (blue and rust-colored areas). Even though a drop of a suspension of the ice-nucleating bacteria *Pseudomonas syringae* (yellow spot on the center leaf of the right-hand side) froze, initial nucleation and freezing started in the stem. (From Wisniewski et al. 1997, courtesy of M. Wisniewski, © American Society of Plant Physiologists, reprinted with permission. See page 740 in Chapter 25.)

### THE TITLE PAGE

Phloem tissue of a bean doubly stained with a locally applied dye (red) and a translocated dye (green). Protein deposited against the plasma membrane and the sieve plate does not impede translocation. A crystalline P protein body is stained by the green dye. Phloem plastids are evenly distributed around the periphery of the cell. (From Knoblauch and van Bel 1998, courtesy of A. van Bel. See page 275 in Chapter 10.)

### THIS PAGE

Time-lapse photograph of a corn coleoptile growing toward unilateral blue light. Unilateral blue light was given from the left. The consecutive exposures were made 30 minutes apart. Note the increasing angle of curvature as the coleoptile bends. (Photograph courtesy of M. A. Quiñones. See page 519 in Chapter 18.)

## PLANT PHYSIOLOGY, Second Edition

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# Preface

IT IS A PRIVILEGE TO PRESENT TO OUR READERS the second edition of *Plant Physiology*, which follows the first edition by seven years. The challenge of condensing, organizing, and synthesizing all the available knowledge in the field was daunting enough at the time of the first edition; the explosion of progress since 1991 makes these tasks even more demanding for the second edition.

The strength of the second edition, like that of the first, lies primarily with the outstanding group of scientists who have contributed their expertise and historical perspectives to this complex effort. They deserve all the credit for selecting the information that best represents the true conceptual advances in the field of plant physiology. Our task has been to ensure that all the topics were adequately covered and that the various topics were presented in a uniform style and level of difficulty. The editorial division of labor was as follows: E.Z. was responsible for Chapters 3, 4, 5, 7, 8, 9, 12, 18, and 25; L.T. was responsible for Chapters 1, 2, 6, 13, 14, 15, 16, 17, 19, 20, 21, 22, 23, and 24; Chapters 10, 11, and 25 have been edited by both of us. Several of the chapter authors from the first edition did not join us for this second edition, but their important contributions are still central to many of the chapters in the book. We wish to thank them for their previous efforts on behalf of the book: George W. Bates, Donald P. Briskin, Anthony L. Fink, Shimon Gepstein, Adrienne R. Hardham, Frank Harold, George H. Lorimer, John W. Radin, Stanley J. Roux, Thomas David Sharkey, Richard G. Stout, Daphne Vince-Prue, and Stephen M. Wolniak.

As in the first edition, much of the credit for integration and pedagogical style belongs to our developmental editor, James Funston. We feel fortunate to have engaged such a wise, creative, and endlessly patient advisor for both the first and second editions of *Plant Physiology*. A major improvement in the preparation of the second edition has been the convenience of using email and the internet, which

enabled us to track down information much more efficiently than before, often from the comfort of our own home offices. The availability of email enabled us to rapidly check the accuracy of information with scientists spread all over the globe. Email also helped us to make pedagogical decisions, since we were able to contact large numbers of people to determine their preferences. Thus the number of colleagues around the world who have provided critical input into the preparation of this book is truly unprecedented.

Perhaps the most important innovation of the second edition is the new publisher, Sinauer Associates. We wish to extend our gratitude to Andy Sinauer for his initial faith in the book and for his continued encouragement during the ensuing months of its preparation; to our editor Nan Sinauer for her infinite patience, adroit decision making, and tireless shepherding of the manu-

scripts from first drafts to final copy; and to Suzette Stephens, Stephanie Hiebert, Chris Small, Janice Holabird, and Jefferson Johnson for their significant contributions.

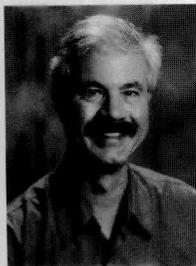
Last but not least, we wish to thank our departmental colleagues, postdoctoral fellows, and students for their precious help and for enduring the extended periods of "total immersion" that were often required to get the job done. Finally, L.T. wishes to thank his wife, Lee Taiz, whose faith in the project sometimes exceeded his own, and whose love and support sustained him whenever the road became bumpy.

*Lincoln Taiz*

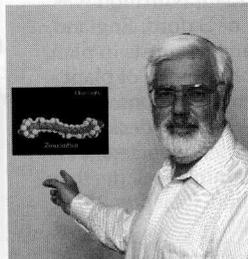
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July 1998

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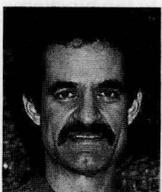
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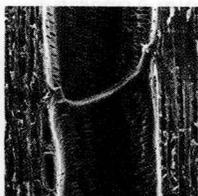
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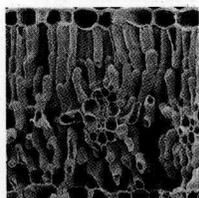
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