Plant Systems Biology

In June 2003, *Plant Physiology* published an Arabidopsis special issue devoted to plant systems biology. The intention of Natasha Raikhel and Gloria Coruzzi, the two editors of this first-of-its-kind issue, was ''to help nucleate this new effort within the plant community'' as they considered that ''despite the power of its promise, systems biology was still in its infancy.'' Now, a few years later, we can ask whether the challenge of ''incorporating information on all genes and proteins in a cell into a composite model of interacting components'' has matured.

Biological systems are complex. Systems biology is based on the premise that their properties cannot be understood by focusing on any one aspect of their highly interacting components. For instance, being sessile organisms, plants should adjust their metabolism and physiology to dynamic changes in their environment, including biotic and abiotic stresses. How does this work? Tight coordination of branched metabolic or signaling networks must be central to the physiological changes needed to continuously face these fluctuating conditions. Moreover, the system's properties of interest often are embodied in its dynamics. For instance, changes in the structure of the network through mutations or epigenetic effects can lead to changes in network dynamics that result in different physiological properties.

Because the functioning of a plant as a system concerns each of its molecular constituents (DNA, RNA, proteins, metabolites, ions, etc.), the expanding development of high-throughput data generation technologies (so-called ''omics'' such as genomics, transcriptomics, proteomics, metabolomics, etc.) made it possible to apply a systems biology paradigm in plant science. Large sets of comprehensive and quantitative data from plant samples grown under a wide variety of conditions have been produced. Massive databases from such high-throughput data, especially in genomics and proteomics, have been created. Clever algorithms and bioinformatics capabilities have been devised to extract all possible biological information about underlying networks. Indeed, the defining characteristic of a systems biology paradigm likely relies on the study of the structure and dynamics of networks through the use of mathematical models. Several plant research institutes have fostered interactions between mathematicians, statisticians, computer scientists, and biologists.

Nonetheless, we are still far from the initial objective of fully understanding how a given system works. The next scientific challenge is to integrate every piece of biological information into a cohesive whole, requiring an iterative process between experimental data and mathematical modeling. Indeed, once data are integrated and models describing the system studied are designed, new data should be produced and reconciled with prior models, and discrepancies between observed data and models should be used to design new perturbations, which are analyzed by means of systematic measurements. Systems biology needs the whole process to be repeated iteratively until model and observed data converge.

This Focus Issue on Plant Systems Biology aims to provide an update on the progress made in this field since 2003 and therefore presents many different aspects of plant science, ranging from collections of physiological data with quantified molecular parts lists (e.g., genes, expression levels, localizations) to abstract mathematical modeling of biological processes. First, in several update articles, we present insights provided by systems biology approaches on topics ranging from Arabidopsis responses to nutritional cues to the foundation of natural genetic diversity. Several of these articles deal with transcriptional, proteomic, metabolic, and/or signaling networks. The different plant systems analyzed range from the intracellular dialog between the chloroplast and the nucleus to dialogs within organs or the entire plant. Second, we present primary research articles relevant to plant systems biology. These research articles provide some mechanistic insight into the regulation and functions of complex systems in diverse areas of plant biology and/or in interactions with other organisms. Together, these articles will be the centerpiece of an online Focus Collection that contains relevant articles published in the 2 years preceding and the 2 years following this issue of *Plant Physiology*.

We think that this Focus Issue on Plant Systems Biology illustrates that dialog between different disciplines is essential for understanding how a plant system works, and we hope that it will stimulate further research. We thank all contributors for providing a snapshot of how plant systems biology is becoming a reality.

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Guest Editors
Plant Physiology

www.plantphysiol.org/cgi/doi/10.1104/pp.110.900314