Editorial: Emerging Technologies for the Study of Plant Environmental Sensing

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Plants and environmental sensing

It is the plant’s autotrophic photosynthetic abilities that allow it to survive in its original location without the need to move its whole life, but it is continuously exposed to changes in environmental conditions, which at times can be very severe. To tackle the many environmental challenges directly, plants have evolved several environmental sensing systems and physiological mechanisms of adaptation (Taiz et al. 2015). Such environmental factors include light, temperature, gravity, water, nutrients, heavy metals, salt, herbivore insects and animals, and pathogens. In nature, plants may face any of those multiple factors at the same one time.

In contrast to plants, animals have various sensory organs. Each organ is suited to a particular environmental factor, and all environmental signals are integrated into the central nervous system. In plants, there is no specialized organ designated for the sensing of environmental conditions. Instead, each plant cell is capable of independently perceiving and responding to environmental signals. In these cells, cross talks of signals first take place before triggering any subsequent responses.

Recent molecular work, most of which has been conducted in Arabidopsis, identified part of the sensing systems and mechanisms underlying physiological reactions in plants. It is now well known that photosignals are perceived by photoreceptor proteins, i.e., phytochrome, cryptochrome, or phototropin, and transmitted to gene expression systems or secondary intracellular signal transduction systems (Galvão & Fankhauser, 2015). In addition to this, recognition systems for plant pathogens or symbiotic microorganisms have also been identified (Dodds and Rathjen 2010). Unfortunately, it is not yet known what the perception systems are for detecting other environmental factors, such as temperature, gravity, drought, water, and nutrients in land plants.

Physiological responses have also been well analyzed at the molecular and cellular levels. Environmental factors usually drive intracellular signal transduction systems, for example, changes in Ca2+ levels (Batistic and Kudla 2012), and/or protein phosphorylation cascades (Osakabe et al. 2013), which drive subsequent changes in gene expression (Knight and Knight 2012). In particular, plant hormones and certain metabolites play very important roles in such physiological processes (Albacete et al. 2014).

New emerging technologies

For more than 20 years, molecular biology techniques largely succeeded in clarifying plant mechanisms involved in environmental perception and physiological responses. This was succeeded by post-genomic analyses (transcriptome, proteome, and/or metabolome), which for the past 10 years have been actively conducted in whole plants or parts of tissues and organs under different environmental conditions (Fester 2015; Hirayama and Shinozaki 2010; Nakayama and Saito 2015; Takahashi et al. 2013; Wee and Dinneny 2010). By studying such analytical data, we now know that rather complex networks are functioning in cells and whole plants (Higashi & Saito 2013). However, to further these analyses, novel analytical methods are required – for which the development and introduction of innovative technology is indispensable.

In this special focus issue, we pay particular attention to three key areas in developing new technologies for the study of plant environmental sensing: 1) comprehensive analyses of gene expression and identification of metabolites in single cells or very small pieces of tissue (a dozen to several tens of cells); 2) structural analysis of macromolecules and organelles working in various biological systems by advanced optical methods; and 3) mechanical manipulation of cells and whole plants at higher spatial resolutions with femtosecond pulsed lasers.

1) Comprehensive analyses of gene expression and identification of metabolites in single cells or small amounts of tissue.

Gene expression analysis in single cells was first developed in the medical field. Dr. Kambara and his colleagues succeeded in quantitatively measuring gene expression in a cultured single human cell (Taniguchi et al. 2009). They applied a slightly different technique for measuring gene expression at the single cell level in plants, mainly because plant cells contain a large central vacuole with various hydrolases, and are tightly connected to neighboring cells via their rigid cell walls. The improved technique was recently demonstrated successful in...
obtaining gene expression data from single plant cells and small pieces of tissues (Kajiyama et al. 2015). In their method, a small piece of tissue was rapidly collected from a fresh plant specimen using a thin metal needle. Because in multicellular plants all cells are embedded in the apoplast, it usually takes a few hours to isolate single cells, during which time gene expression patterns could easily change. Thus, instant clipping of a small piece of tissue with the needle has made it possible to more accurately detect gene expression patterns at that time. Using this technique, Nito et al. (2015) demonstrated that the gene expression responses of cotyledons and the shoot apical region to the shade stimulus were quite different. In addition, Ohnishi et al. (2015) were able to precisely measure specific gene expression in palisade cells of Saintpaulia leaf.

Plant metabolomics is becoming a very popular method to identify metabolic pathways and to assess the quality of agricultural products (Kusano et al. 2015). For this, whole plants or valuable parts have been used as starting biological materials. Given that key substances, such as plant hormones or secondary metabolites do not equally localize in plants, it is often necessary to be able to detect cell or tissue-specific localization of those substances. For this purpose, two novel technologies have been developed; one is imaging mass spectroscopy and the other is single cell mass spectroscopy. Takahashi et al. (2015) reported a newly developed imaging mass spectroscopy system, which is specialized for plant tissues. They succeeded in detecting tissue-dependent localization of metabolites at 20 μm distance resolution in whole seedlings and sections of more mature plants. Masujima and his colleagues first succeeded in measuring metabolites in a single rat cell (Mizuno et al. 2008). Afterwards Lorenzo et al. (2012) applied this method to individual plant cells. In this issue, Simizu et al. (2015) attempted to measure plant hormones in individual Vicia faba cells using live-single cell mass spectroscopy. By doing so, cell-dependent localization of ABA and JA-Ile was detected.

2) Structural analysis of specific macromolecules and organelles.

New technologies are also being developed in order to analyze the molecular structure of bio-molecules. Changes in protein structure that are dependent on environmental conditions are uncovering a possible role in signal transduction in the cell (Okajima et al. 2014; Kashoyja et al. 2015). The recent development of a high-energy radiation system similar to synchrotron radiation was successfully used to determine many 3D protein arrangements and to predict new molecules that affect protein function. Such an instrument has been employed to observe the 3D structure of non-crystalline particles at a resolution of several tens of nanometers. For example, Takayama et al. (2015) showed X-ray diffraction imaging of chloroplasts in red microalgae in vivo by using the X-ray free electron laser in Spring-8 (Super photon ring-8 GeV; http://www.spring8.or.jp/en/about_us/whats_sp8/) in Japan. Vijayan et al. (2015) further discuss how synchrotron radiation is quite effective for observing spatial distribution patterns of biomolecules in plant sections.

3) The mechanical manipulation of cells and whole plants with femtosecond pulsed lasers.

The new technologies described in the above two categories all belong to the fields of molecular and cell biology. While molecular biology has proven a great success in understanding the molecular mechanisms of plant behavior, the physical manipulation of cells and whole plants was not as popular in contrast to other fields, such as zoology and medical sciences. New physical manipulation technologies have more recently been developed for the analysis of physiological responses for example, laser dissection, microinjection, etc. Amongst these, femtosecond laser beam technology has been employed to conduct laser microsurgery by virtue of its non-destructiveness (Kohli & Elezzabi 2009). Oikawa et al. (2015) used mechanical stimulation of femtosecond pulsed lasers to demonstrate that the physical interactions between peroxisome and chloroplasts is dependent on light conditions. In this issue, Goto-Yamada et al. (2015) review biological functions of peroxisomes and related organelle interactions. The femtosecond pulsed laser is not only useful for mechanical stimuli but also for the physical manipulation of the cells (Hosokawa et al. 2011).

Future perspectives

In this issue, we have focused on some of the new technologies that have been recently introduced in the plant science field. When considering the history of science, the development of new technologies has been at the heart of many new ground breaking achievements. At present it may not be so easy for all scientists to access some of these techniques. However, in future these new techniques should become more accessible either directly or through collaborations.

We hope that the present special focus issue encourages readers to understand the opportunities offered by some of the new technologies described and attempt to apply such resources to their own research. We believe that new technologies are quite valuable for the study of plant environmental sensing, as well as many other areas of plant science.

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