Signalling crosstalk in plants: emerging issues

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Abstract

The Oxford English Dictionary defines crosstalk as ‘unwanted transfer of signals between communication channels’. How does this definition relate to the way in which we view the organization and function of signalling pathways? Recent advances in the field of plant signalling have challenged the traditional view of a signalling transduction cascade as isolated linear pathways. Instead the picture emerging of the mechanisms by which plants transduce environmental signals is of the interaction between transduction chains. The manner in which these interactions occur (and indeed whether the transfer of these signals is ‘unwanted’ or beneficial) is currently the topic of intense research.

Key words: Crosstalk, plant signalling, transduction chains.

Introduction

A number of key questions regarding the way in which we view crosstalk in plant signalling are already emerging. Therefore, in April 2003, the Plant Development and Cell sections of the Society for Experimental Biology hosted a two and a half day session entitled Crosstalk in Plant Signal Transduction to explore these issues. As organizers of the session, our aim was to adopt a novel approach to this topic examining it from a range of perspectives beginning with whole organism–environment interactions through to studies of the molecular identity of individual signalling components and the mechanisms of their interactions. In doing so, we felt that the range of techniques being used to study crosstalk at all levels, from physiological studies to the application of ‘omics’ technologies, highlight the timeliness of this approach. The focus of the meeting was to examine crosstalk induced by both biotic and abiotic stresses, and in response to essential natural environmental variables such as light.

One of the key questions addressed during the symposium was that of what constitutes crosstalk and whether crosstalk actually occurs in plant signalling. Perhaps the most frequently proposed model is of signalling pathways sharing common components. If this is truly viewed as representing crosstalk it is imperative that there should be transfer of information between signalling pathways through these common components, and that this information transfer has the potential to alter the output of the different signalling pathways. Practically, this would mean a requirement for the use of a single component by two different pathways within the same cell at the same point in time. The presence of similar components in two or more signal transduction pathways does not necessarily imply crosstalk. These points were addressed in presentations by Marc Knight (Oxford, UK) and Jian-Kang Zhu (Arizona, USA). Marc Knight highlighted the importance of demonstrating a flow of information through components shared between two or more signalling pathways. However, the demonstration of this level of interaction represents a significant challenge. Jian-Kang Zhu (Arizona, USA) reiterated this statement, but, in addition, questioned whether it was as yet too early to be discussing crosstalk given the limited number of signalling components identified in most signalling pathways in plants. An alternative to the view of signalling cascades as linear pathways with the potential for crosstalk is that the perception of environmental signals involves a network of signalling components. This type of model enables multiple inputs to affect multiple outputs. Alistair Hetherington (Lancaster, UK) presented evidence for the organization of signalling pathways into complex networks but questioned whether such complex interactions should be described as crosstalk per se since the exchange of information between hubs and nodes is an inherent property of networks. However, he noted that more data...
are required before definitive conclusions can be reached about the organization of signalling systems into networks. Peter McCourt (Toronto, Canada) went further than this and used the analogy between the complexities of the map of the Tokyo underground system and the ‘topology’ of signalling to question whether building a map of signalling pathways in Arabidopsis by the genetic identification of signalling components is a relevant approach. He commented that the map of the Tokyo underground system provides a clear overview of the connections within the system but provides little information about how the system works and compared this to our current understanding of signalling pathways in plants. All of these issues were discussed under the broad heading of crosstalk, which, for the purposes of the meeting, were divided into three main areas, namely crosstalk: an ecological perspective, signalling in abiotic and biotic stress, and light signalling and clocks.

**Crosstalk: an ecological perspective**

Presentations given by Ian Baldwin (Max Planck, Jena), Jennifer Thaler (Toronto, Canada) and Nigel Paul (Lancaster, UK) addressed the issue of crosstalk in signalling from an ecological perspective describing their work on plant–herbivore, plant–pathogen, and plant–herbivore–pathogen (tripartite) interactions, respectively. These talks described ecological and molecular tools for investigating crosstalk, highlighting how these two disciplines of research are coming together. Ian Baldwin described the generation of a herbivore-specific transcriptional imprint that influences the response of plants to future pest attacks. Jennifer Thaler presented a talk entitled ‘Ecological consequences of signalling crosstalk in tomato plants’ in which she presented evidence for crosstalk between the jasmonic and salicylic acid signalling pathways under field conditions. Nigel Paul concluded the session in which he positioned the study of tripartite interactions within the signalling arena.

**Signalling in biotic stress**

Richard Dixon (Samuel Roberts Noble Foundation, USA) opened the session on signalling in biotic stress by discussing signals for local and systemic responses of plants to pathogen attack. Thomas Boller (Basel, Switzerland) talked about his work on sensing bacterial elicitors. Andrea Ludwig (JIC, UK) and Heri Hirt (Vienna, Austria) discussed the role of kinases in biotic stress signalling. Andrea Ludwig considered CDPKs as molecular switches between biotic and abiotic stress responses and Heri Hirt discussed the link between signal and form, describing the role of stress-induced MAP kinases in root hair formation. Guy Kiddle (Rothamsted, UK) also presented a paper on the involvement of genes modulated by vitamin C content in plant defence and development.

**Signalling in abiotic stress**

Talks by Alistair Hetherington, Marc Knight, Jian-Kang Zhu, and Peter McCourt in the session on abiotic stress signalling provided interesting insights into the question of what constitutes crosstalk and whether crosstalk actually occurs in plant signalling. Marc Knight and Jian-Kang Zhu presented a genetic analysis of crosstalk in cold, drought, and salt signalling. This was complemented by Moto Seki (RIKEN, Yokohama, Japan) using a genomics approach in his description of expression profiling using Arabidopsis full-length cDNAs under abiotic stress conditions. Marc Knight also described links between cold and drought signalling to pathways using active oxygen species. The talk by Radhika Desikan (UWE, Bristol) highlighted further the role of active oxygen species in plant signalling and the crosstalk that occurs between ABA, hydrogen peroxide, and nitric oxide signalling in stomatal guard cells. Alistair Hetherington talked extensively about crosstalk in guard cell signalling pathways and provided a challenging model in which individual signalling components might be organized into networks. By contrast, Peter McCourt discussed interactions between development and hormone signalling in Arabidopsis, but questioned whether building a map of signalling pathways in Arabidopsis by the genetic identification of signalling components is a relevant approach for studying crosstalk. The theme of ABA signalling and the interaction with other signalling pathways was further developed by Bob Sharp (Missouri-Columbia, USA) using a physiological approach to examine the role of ethylene suppression in the maintenance of root and shoot growth by ABA. Susan Gibson (Minnesota, USA) completed this session by describing the interactions between sugar and phytohormone response pathways as ‘navigating a signalling network’.

**Light signalling and clocks**

The concluding session of the session was dedicated to crosstalk in light signalling and clocks. Jennifer Nemhauser (Salk Institute, USA) and Alex McCormac (Southampton, UK) presented papers on light signalling and development. Jennifer Nemhauser discussed signal integration during photomorphogenesis in Arabidopsis seedlings, and Alex McCormac presented data on the interaction of light and plastid signals mediating early stages of chloroplast development. Garry Whitelam (Leicester, UK) and Andrew Millar (Warwick, UK) presented papers on phytochrome signalling. Garry Whitelam discussed light signals, phytochromes and crosstalk with other environmental cues, whereas
Andrew Millar focused on phytochrome photoreceptor functions in the circadian clock and, specifically, the question ‘is biological regulation modular?’ Finally, Antony Dodd (Cambridge, UK) continued the theme of circadian biology with a talk describing his work on the role of cytosolic calcium circadian signalling in stomatal guard cells.

Conclusion

This Special Issue of the *Journal of Experimental Botany* provides a flavour of the session and the topics discussed, presenting a mix of review and experimental papers written by invited participants. There are clearly a number of issues that have emerged from the session that are central to our understanding of the interactions that take place between signalling pathways and/or their individual components. Many of these are equally as relevant to studies of whole organism–environment interactions as they are to those of interactions at the cellular and molecular level. Perhaps the most prominent of these is the need for a more in-depth understanding of the mechanisms by which plants respond to environmental cues. Currently, we only have detailed information for a limited number of pathways and for many of these only a handful of components have been identified. In the natural environment, plants are exposed to, and respond to, a plethora of stimuli simultaneously. Therefore, we urgently need more information before we can adequately address questions such as what constitutes crosstalk, or whether crosstalk actually occurs in plant signalling. Furthermore, although we frequently consider crosstalk as a positive regulatory attribute of signalling systems we also need to consider the possibility that under certain circumstances crosstalk may represent the unwanted transfer of signals as the dictionary definition suggests (Oxford English Dictionary, 2003). Perhaps on a lighter note, we should not lose sight of the wider definition of crosstalk as ‘witty conversation; repartee’ (Oxford English Dictionary, 2003).

References