Preface

Novel developments in plant organellar signalling

Subcellular compartmentation is a hallmark of all eukaryotic cells and in the past has mostly been discussed in terms of a separation of different metabolic pathways. However, in the cellular context these different activities need to be coordinated and adjusted to changing environmental conditions involving a great variety of different signalling mechanisms and pathways. While some of them have been known for many years, a number of completely novel pathways and signalling mechanisms have been discovered only recently. They involve a surprisingly broad range of metabolites, secondary messengers and hormones, as well as proteins such as transcription factors and protein kinases. At the time of the last Journal of Experimental Botany special issue on organellar signalling in 2012 (e.g. see Teige, 2012) there was a focus on identification of novel components and description of general mechanisms. Much progress has been achieved since then, particularly in the latter area, and therefore here we emphasize emerging novel connections between different signalling pathways and the specific mechanisms involved.

Reviews – novel connections and specific mechanisms

Reviews comprise the first part of the special issue, and Kmiecik et al. (pages 3793–3807) introduce the subject, briefly summarizing different signalling pathways involved in organellar signalling and highlighting emerging topics, including a group of transcription factors and their potential regulation by phosphorylation or crosstalk with hormones. Opportunities for future research are noted, with a particular focus on chloroplasts. The following review by Wagner et al. (pages 3809–3829) summarizes the role of mitochondria in organellar signalling and compares the regulation of mitochondrial Ca^{2+} signalling in plant and animal mitochondria. Both mitochondria and chloroplasts are a potential source of reactive oxygen species (ROS), which are increasingly being identified as important signalling molecules. Their production and role in signalling is described by Mignolet-Spruyt et al. (pages 3831–3844), and also addressed in the review by Serrano et al. (pages 3845–3854) – they emphasize in particular the emerging role of chloroplasts as central integrators of environmental signals, and their crucial functions during the establishment of plant defence signalling.

Moving from the organelles to signalling molecules and mechanisms, the following reviews focus on the role of protein phosphorylation and kinases. First, the subcellular localization and targets of calcium-dependent protein kinases are covered by Simeunovic et al. (pages 3855–3872), with the aim of better understanding the complexity of cellular Ca^{2+} signalling and crosstalk with other kinase pathways based on specific localization of the enzymes. The following survey of protein phosphorylation in plastids by Baginsky (pages 3873–3882) gives an overview of the current status of phosphoproteome analyses in plastids of Arabidopsis, rice and maize, and compares the data in the light of phosphorylation site conservation. This is followed on by Grieco et al. (pages 3883–3896), who summarize our current knowledge of thylakoid protein phosphorylation sites involved in the regulation of photosynthesis in plants and green algae from an evolutionary perspective. This approach has uncovered novel phosphorylation hotspots and could help to identify phosphosites with potential functional implications.

The opinion paper by Roustan et al. (pages 3897–3907) again extends this approach to gain insights into the evolutionary development of cellular signalling by analysing the highly conserved AMPK-TOR signalling pathway, the key regulator of cellular energy homeostasis in the three domains of life. This cellular signalling module is highly relevant as it involves coordination between energy metabolism and growth processes in different subcellular compartments, with fundamental implications beyond plants.
Retrograde signalling, light and calcium signalling

In the second part of the special issue research papers address the role of different components of retrograde signalling pathways, light and calcium signalling, as well as protein phosphorylation. In their paper Sun et al. (pages 3909–3924) report the identification and characterization of mitochondrial transcription termination factor 4 (mTERF4), which cooperates with GUN1 to regulate plastid gene expression and plastid retrograde signalling. Magnesium chelatase has also been implicated in retrograde signalling in higher plants, and in their analysis of chlorophyll biosynthesis genes Brzezowski et al. (pages 3925–3938) show that the Mg chelatase CHLI2 cannot substitute for CHLI1 in chlorophyll synthesis and retrograde signalling in Chlamydomonas reinhardtii.

Light-harvesting proteins are a typical target of retrograde signalling pathways, but they also need to react to external stimuli. This becomes particularly relevant in highly variable ocean environments, and this is further described by Taddei et al. (pages 3939–3951) who show how multiple stress signalling pathways regulate LHCX family gene expression in the diatom Phaeodactylum tricornutum to efficiently attune the acclimation response. Light signals are also frequently employed in developmental processes or physiological acclimation processes in higher plants. Blue light, for example, presents the major stimulus for phototropism or chloroplast positioning in response to changing light conditions. In their study, Labuz et al. (pages 3953–3964) show that the localization of loosely bound calcium in Arabidopsis mesophyll changes under strong blue light in the wild type, but not in phot2 and phot1 phot 2 mutants. This indicates that PHOT2 is involved in calcium homeostasis and further supports the close connection between blue light signals and Ca$^{2+}$ signalling.

Calcium signalling, protein phosphorylation, transcriptional regulation

Ca$^{2+}$ signals in amyloplasts and chloroplasts of Arabidopsis cell suspension cultures are described by Sello et al. (pages 3965–3974), who dissect stimulus-specific differential Ca$^{2+}$ responses of non-green plastids versus chloroplasts to several environmental cues using the Ca$^{2+}$ reporter aequorin. Lohscheider et al. (pages 3975–3984) show that the core plastoglobule proteome consists of 30 proteins and several transiently associated proteins. Based on careful evaluation of published proteomics data, they conclude that nine of these proteins have one or more serine or threonine phosphorylation sites. Ruge et al. (pages 3985–3996) show that the calmodulin-like proteins AtCML4 and AtCML5 are targeted to the endomembrane system by an N-terminal signal-anchor sequence, where they localize as single-pass membrane proteins at the interface between Golgi and the endosomal system. They further speculate that AtCML4 and AtCML5 might provide a basis for calcium regulation of endosomal vesicle transport in higher plants. Although calcium signalling is usually considered to be a typical eukaryotic signalling mechanism, increasing evidence has emerged of an important role in prokaryotes. In this context Walter et al. (pages 3997–4008) show that calcium affects the primary cellular metabolism of Anabaena under conditions replete in both combined nitrogen and inorganic carbon. They further report that opposite transcriptome responses to calcium treatments occur for nitrogen- and carbon-related processes.

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References

Baginsky S. 2016. Protein phosphorylation in chloroplasts – a survey of phosphorylation targets. Journal of Experimental Botany 67, 3873–3882.

Brzezowski P, Sharifi MN, Dent RM, Morhard MK, Niyogi KK, Grimm B. 2016. Mg chelatase in chlorophyll synthesis and retrograde signaling in Chlamydomonas reinhardtii: CHLI2 cannot substitute for CHLI1. Journal of Experimental Botany 67, 3925–3938.

Grieco M, Jain A, Ebersberger I, Teige M. 2016. An evolutionary view on thylakoid protein phosphorylation uncovers novel phosphorylation hotspots with potential functional implications. Journal of Experimental Botany 67, 3883–3896.

Kmieciak P, Leonardelli M, Teige M. 2016. Novel connections in plant organelar signalling link different stress responses and signalling pathways. Journal of Experimental Botany 67, 3793–3807.

Labuz J, Samardakiwicz S, Hermanowicz P, Wyroba E, Pilarska M, Gąbryś H. 2016. Blue light-dependent changes in loosely bound calcium in Arabidopsis mesophyll cells: an X-ray microanalysis study. Journal of Experimental Botany 67, 3953–3964.

Lohscheider JN, Friso G, van Wijk KJ. 2016. Phosphorylation of plastoglobular proteins in Arabidopsis thaliana. Journal of Experimental Botany 67, 3975–3984.

Mignolet-Sprüty L, Xu E, Idänheimo N, Hoeberichts FA, Mühlenbock P, Brosché M, Van Breusegem F, Kangasjärvi J. 2016. Spreading the news: subcellular and organelar reactive oxygen species production and signalling. Journal of Experimental Botany 67, 3831–3844.
Roustan V, Jain A, Teige M, Ebersberger I, Weckwerth W. 2016. An evolutionary perspective of AMPK-TOR signaling in the three domains of life. Journal of Experimental Botany 67, 3897–3907.

Ruge H, Flosdorff S, Ebersberger I, Chigri F, Vothknecht UC. 2016. The calmodulin-like proteins AtCML4 and AtCML5 are single-pass membrane proteins targeted to the endomembrane system by an N-terminal signal anchor sequence. Journal of Experimental Botany 67, 3985–3996.

Sello S, Perotto J, Carraretto L, Szabó I, Vothknecht UC, Navazio L. 2016. Dissecting stimulus-specific Ca$^{2+}$ signals in amyloplasts and chloroplasts of Arabidopsis thaliana cell suspension cultures. Journal of Experimental Botany 67, 3965–3974.

Serrano I, Audran C, Rivas S. 2016. Chloroplasts at work during plant innate immunity. Journal of Experimental Botany 67, 3845–3854.

Simeunovic A, Mair A, Wurzinger B, Teige M. 2016. Know where your clients are: subcellular localization and targets of calcium-dependent protein kinases. Journal of Experimental Botany 67, 3855–3872.

Sun L, Tian J, Zhang H, Liao H. 2016. Phytohormone regulation of root growth triggered by P deficiency or Al toxicity. Journal of Experimental Botany 67, 3909–3924.

Taddei L, Rocco Stella G, Rogato A, et al. 2016. Multisignal control of expression of the LHCX protein family in the marine diatom Phaeodactylum tricornutum. Journal of Experimental Botany 67, 3939–3951.

Teige M. 2012. Preface. Special Issue: Organellar Signalling. Journal of Experimental Botany 63, 1523–1524.

Wagner S, De Bortoli S, Schwarzländer M, Szabó I. 2016. Regulation of mitochondrial calcium in plants versus animals. Journal of Experimental Botany 67, 3809–3829.

Walter J, Lynch F, Battchikova N, Aro E-M, Gollan PJ. 2016. Calcium impacts carbon and nitrogen balance in the filamentous cyanobacterium Anabaena sp. PCC 7120. Journal of Experimental Botany 67, 3997–4008.