

Why the taxpayer profits from plant cell biology—special issue “Applied Plant Cell Biology”

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Plant cell biologists are often perceived as the guys that produce esthetically appealing images, and are deeply rooted in the realm of pure science, far away from anything that might be biotechnologically relevant. Why should the taxpayer fund this curiosity-driven type of research? Maybe, because science is a central part of human culture and therefore should be supported in the same manner as the public funds theatres or art exhibitions? This view is frequently encountered in the West. If this view were true, why should a pragmatic country like China invest so much effort to develop plant cell biology—by the way manifested by a rising number of cell-biological publications from China also in this journal. These considerations motivated an exploratory symposium on “Applied Plant Cell Biology” in March 2011 funded by the SinoGerman Science Center, where 40 scientists from both countries highlighted different aspects of the interface between plant cell biology and application.

The pronounced developmental and metabolic capacities of plant cells provide the base of agriculture and green biotechnology and have been studied very intensively with respect to its genetic aspects. The so-called Green Revolution has ensured a reliable and cost-efficient supply with food resources to a growing population. A major part of this success story is based on three factors: advances in plant nutrition, advances in plant protection, and advances in plant genetics. The challenge of the coming years will be to reconcile increased agricultural productivity with sustainability. The potential of plant nutrition and plant protection has been basically exploited, what remains, are advances in

generating new genotypes with improved productivity, tolerance to biotic and abiotic stresses, and improved or even novel metabolic potential. However, it becomes increasingly clear that the potential of applied plant science can only be fully exploited when we understand the cellular mechanisms such as compartmentalisation, intracellular transport, cell differentiation, and communication. To understand biotechnologically relevant molecular mechanisms for stress tolerance and accumulation of interesting compounds, we need a strong background in molecular cell biology. Therefore the current special issue exemplarily has selected three issues from this symposium highly relevant for biotechnological application: control of plant architecture through cytoskeleton and cell wall, control of development by signals, and the impact of cellular compartmentalisation for plant metabolism.

Control of plant architecture through cytoskeleton and cell wall

Plant architecture has emerged as a new and promising issue in plant biotechnology. In rice, for instance, steeper leaf angles that allow the sunlight to penetrate deeper into the canopy, shorter internodes that increase lodging resistance, or suppression of tillers with unfilled grains, have been identified as important traits for breeding high-yielding cultivars. These architectural traits are under control of the cytoskeleton. Cortical microtubules regulate plant length by control of cellulose orientation, but also act as sensors and integrators for stimuli such as mechanic load, gravity, osmotic stress, cold, and pathogen attack. The contribution by Nick (2012) in this issue gives a survey on these plant-specific functions of microtubules and explores the potential of microtubule-based strategies for biotechnological

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application by highlighting representative case studies. The functional diversification of plant microtubules is brought about by novel classes of their associated proteins, among them specific classes of kinesin motors with often unexpected properties. The contribution by Li et al. (2012) in this issue summarises our knowledge about recently discovered novel kinesins that, in addition to their microtubule-binding activity act as transcription factors regulating gibberellin biosynthesis genes. The mechanically rigid microtubules are intimately linked with the flexible actin filaments establishing a network endowed with tensegrity. Linker proteins between the two cytoskeletal elements, although inferred already for a long time, have until recently remained elusive in plant cells. The recent discovery that specific classes of formins, known from their role in actin organisation, interact with microtubules both *in vitro* and *in vivo* has led to new insights on the biological function of these cytoskeletal proteins which are reviewed by Wang et al. (2012) in the current issue. All these cytoskeletal reorganisations ultimately control morphogenesis by adjusting the extensibility of the cell wall redirecting turgor pressure into the long axis of the cell. The extensibility has to be constantly adjusted even after cellulose microfibrils had been deposited. This adjustment also includes modifications of the embedding matrix, for instance, the pectins, a functionally and structurally diverse class of galacturonic acid-rich polysaccharides that can be modified by pectin methylesterases. The contribution by Wolf and Greiner (2012) in the current issue summarises the knowledge about these enzymes, and highlights their function in growth control for primordial expansion in the shoot apical meristem.

Development

Plant development is highly flexible and has to be tuned with the environment, with light being the central environmental signal. Three different groups of photoreceptors, phytochromes, cryptochromes, and phototropins, have been discovered in seed plants. These photoreceptors have to be linked to specific developmental programmes, such as cell growth in seedlings. As explored by the contribution of Svyatyna and Riemann (2012) in the current issue, induction of the jasmonate biosynthetic pathway is required for normal photomorphogenesis of rice, which contrasts the situation in the dicotyledonous model plant *Arabidopsis*. By conjugation with the amino acid isoleucin, the jasmonate signal is diversified and used for a sophisticated and multifaceted cross-talk between different light qualities and other hormonal and developmental pathways. The climax of plant development is the flower. In Angiosperms, this reproductive organ shows great diversity in organisation, shape, and colour. The regulatory network controlling flower

development has been studied intensively for *Arabidopsis* and *Antirrhinum* as models. However, it remains questionable to what extent floral models can be transferred to other plants. This is exemplarily investigated in the contribution by Xu and Bai (2012) in the current issue for the unisexual cucumber flower. In a thoughtful analysis of developmental physiology and evolutionary considerations, they revisit the concept of plant sexuality and show the limitation of models that are simple because they lack integrity, or to quote it in their words: “knowing, how an organ development is inhibited may not necessarily be useful for understanding how an organ is formed.”

Plant metabolism and compartmentalisation

Plants produce a vast array of natural products (primary and secondary metabolites), many of which have evolved to confer adaptive advantages against biotic and abiotic stresses in natural environments. Often, certain species produce and accumulate particular metabolites. The transcription factors controlling plant metabolic pathways leading to biosynthesis of flavonoids, glucosinolates, lignins, and of terpenoid indole alkaloids have been isolated and characterized. This information can now be used to decipher the molecular mechanisms responsible for coordinate induction of transcriptional networks in particular cell types. The contribution by Czettel et al. (2012) in the current issue exemplarily reviews the already detailed knowledge on specificity and regulatory functions of R2R3 MYB proteins that regulate specific branches of flavonoid biosynthesis in the important crop plant grapevine. This class of transcription factors allows to trigger specific branches of the pathway—there are factors inducing specifically flavonol synthesis, others trigger the formation of proanthocyanidins, and a third group the synthesis of the coloured anthocyanins. This versatile system of genetic switches might be exploited for metabolic engineering of the medically and agronomically interesting flavonoid pathway. The regulation of metabolic pathways often involves intensive traffick of intermediates between different tissues or between different compartments of individual cells. The impact of metabolic compartmentalisation and its evolutionary development is exemplarily dissected in the contribution by Birke et al. (2012) in the current issue for sulphur metabolism. Sulphur is one of the most versatile elements in life due to its reactivity in different oxidation and reduction states. Reduced sulphur together with iron is believed to have functioned in early electron transport processes during pro-life development on earth. In phototrophic organisms, the redox properties of sulphur in proteins and of sulphur-containing metabolites are particularly important for the mediation between the reductive assimilation processes of

photosynthesis and reactive oxygen species that arise as by-products of electron transport chains in chloroplasts and mitochondria. In higher plants, cysteine is distributed between cytoplasm, plastids, and mitochondria, whereas in *Chlamydomonas* it is exclusively found in chloroplasts. In mosses, O-acetylserine(thiol)lyases, the enzymes catalysing the final step of cysteine synthesis, are partially dually located in plastid and cytoplasm representing a missing link in the evolutionary series leading to sulphur compartmentalisation. To study the dynamics of cellular compartments requires tools that allow to visualise these compartments in vivo. The contribution by Chen et al. (2012) in the current issue deals with novel tools that allow to monitor compartmentalisation in living plant cells. These include fluorescent dyes (such as the biarsenic fluorophore system), novel fluorescent proteins such as pH-based fluorescent proteins, photoconvertible fluorescent proteins, and Quantum Dots. Metabolic pathways are also monitored by the plant itself and can be used to sense stress conditions, as pointed out in the contribution by Pfannschmidt and Yang (2012) in the current issue. They show for photosynthesis that the proton gradient and the redox state of the photosynthetic electron transport are used as signals to sense the efficiency of the photosynthetic process and to adjust by posttranslational modification the protein complexes in the context of stress adaptation.

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