Signals, Their Perception, and Primary Plant Metabolism.  
The Third International Symposium  
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The Third International Symposium on Signals, Their Perception, and Primary Plant Metabolism was organized by a consortium of five German research institutions (Collaborative Research Center SFB 429) within a framework of the research program on Molecular Biology, Energetics, and Regulation of Primary Plant Metabolism. This event attracted about 200 participants from many countries.

The study of primary plant metabolism has become especially important in relation to active attempts of the researchers of postgenomic era to comprehend the molecular mechanisms of its regulation as related to varying availability of the major nutrients such as carbon and nitrogen and to the environmental changes. The main goals of such study are (a) elucidating the mechanisms that operate the sensor systems and the signaling networks which perform the key role in the plant cell response to changes in the availability of nutrients and environmental conditions and (b) looking into the nature of subsequent metabolic reorganization and the role of individual genes, groups of genes, and gene networks. The symposium demonstrated that the researchers attempted to formulate the detailed notions of primary plant metabolism as a dynamic process. The reports dealing with the two most actively investigated regulatory systems involving molecular sensors: sugar signaling and redox signaling—demonstrated rapid accumulation of information on this issue in the course of the latest decade.

The Symposium program dealt with five main topics: (1) the pathways and control of metabolism; (2) translocation; (3) sensors and signaling; (4) supramolecular complexes; (5) regulation and mechanisms of photosynthesis. Along with oral reports, a poster session (80 posters) made it possible to thoroughly discuss and exchange opinions on a wide range of issues.

METABOLISM: PATHWAYS AND REGULATION

The report of M. Stitt (Golm, Germany) dealt with the circadian rhythms in gene expression. In order to elucidate the participation of sugars in the regulation of diurnal cycle in plants, the response of Arabidopsis thaliana to the changes in carbon supply was thoroughly analyzed. To this end, the researchers employed the approaches used in genomics and proteomics as well as the multilevel phenotyping (expression profiling, robotized enzyme assays, and metabolic profiling). Sugars were shown to considerably affect the diurnal profile of gene expression. The comparison of gene expression in the wild type and starch-free pgm mutant plants showed that sugars modified the expression of many genes of this type. This work resulted in the identification of candidate genes involved in the sugar-dependent signaling pathways, including the genes associated with the synthesis of trehalose 6-phosphate, phytohormone production, signal perception, protein stability, and regulation of transcription. L. Sweetlove (Oxford, Great Britain) made a report about regulation of metabolic networks. This researcher analyzed in great detail the current notions of multiple levels of regulation of the activity of the enzymes participating in the metabolic networks and maintaining their operation at the level corresponding to the changes in the biochemical and physiological state of the organism.

In order to produce a comprehensive and integrated picture, attempts have been recently made to employ a systemic approach to the estimation of different levels of metabolic regulation. One more level of regulation to be taken into consideration concerns the interactions between the proteins and the specific interactions between the successive enzymes in a particular metabolic pathway. The existence of such complexes called metabolons was discovered not long ago, and presently they are actively investigated. In his report, Sweetlove focused his attention on the enzymes of glycolysis forming large protein complexes at the surface of outer mitochondrial membrane, which entirely meet criteria of metabolon. Using two-dimensional native gel electrophoresis, the researcher obtained new data concerning the formation and operation of a specific substrate channel produced by the glycolytic enzymes within this metabolon.

A. Smith (Norwich, Great Britain) generalized the latest data concerning the pathways of starch degradation, which have not yet been included in the textbooks. Starch degradation at night in the leaves of arabidopsis was found to considerably differ from the generally accepted pattern. For instance, the enzyme glucan-H$_2$O-dikinase (sex1) apparently cleaves starch by means of exogenous (and not endogenous) interactions with the substrate. Linear glucans derived from starch...
granules are hydrolyzed by β-amylase to maltose, which is exported from the chloroplasts by a recently discovered maltose carrier (Mex1). In the cytosol, maltose is the substrate for trans-glucosylation producing glucose and a glucosylated acceptor molecule. In the organs and tissues that store starch (for instance, in the graminous endosperms and in the legume seeds), the process of starch breakdown differs from the process of starch degradation in arabidopsis described above.

Other interesting reports made at this session dealt with the synthesis of sucrose in the leaves of tobacco (F. Börnke, Erlangen, Germany), the role of the enzyme glycogen synthase kinase 3 (MSK4) in the mechanism of arabidopsis resistance to stress (C. Jonak, Vienna, Austria), analysis of the enzyme activities in the arabidopsis embryos associated with carbon metabolism (S. Baud, York, Great Britain), and the role of carbohydrates in the metabolic control of pollen germination and the growth of pollen tube (T. Roitsch, Würzburg, Germany). S. Binder (Ulm, Germany) described a gene family of aminotransferases working on the side chains of amino acids in *A. thaliana* (AtBCAT). New data concerning compartmentation of glutathione biosynthesis in arabidopsis were presented by A. Meyer (Heidelberg, Germany).

**TRANSLOCATION**

This session mostly dealt with the transport proteins of the organelles. U.-I. Flugge (Cologne, Germany) reported three classes of phosphate carriers from the inner chloroplast membrane encoded by *pPT* genes. These carriers perform a key role in the active exchange of precursor molecules between the cytosol and the stroma of plastids. The influence of these carriers on the carbon metabolism in the daytime and at night and on starch biosynthesis was discussed. While triose phosphate translocator (TPT) is important for the daytime metabolic pathway of newly fixed carbon, dark partitioning of carbon depends on other carriers. Starch breakdown is accompanied by the formation of maltose, which is exported by the maltose carrier MEX1 and maltotriose, which is converted to glucose apparently exported by the glucose carrier pGlcT (a representative of TC family). In *C. elegans*, a presumable function of phosphoenolpyruvate translocator (PPT) is the import of phosphoenolpyruvate (PEP) and not its export. PEP acts as a precursor in the shikimate pathway located in plastids. In the report highlighting the role of ATP/ADP translocator in the plastids, E. Neuhau (Kaiserslautern, Germany) presented the results suggesting a direct participation of this carrier in the regulation of the pathways of chlorophyll and heme biosynthesis. Thus, the physiological function of this translocator was established 37 years after its discovery in the isolated chloroplasts.

The report of R. B. Klösgen (Halle, Germany) dealt with one of the four pathways of protein transport in the thylakoid membrane of chloroplast—ΔpH-dependent twin arginine translocation (Tat) notable for the transfer of folded polypeptide chains. This pathway of protein translocation requires a signal peptide carrying a double pair of arginine residues located upward from the hydrophobic core domain. The mechanism of protein translocation involving Tat carrier was investigated using a chimeric precursor polypeptide.

**SENSORS AND SIGNALING**

This session addressed the whole range of issues related to plant sensors and signal mechanisms. B. Buchanan (Berkeley, United States) dwelt on the prospects for broadening the horizons of redox regulation. Special attention was paid to revealing new types of redox regulation involving thioredoxins in the processes of communication between the organs and organelles and in the developmental processes. The methods of proteomics made it possible to identify over 200 functional proteins interacting with thioredoxins in the course of numerous processes. Thioredoxins were found to play a specific role in the seeds of dicots (for instance, in *Medicago*).

The results of investigation of redox regulation of a nuclear gene 2CPA encoding chloroplastic 2-Cys-per-oxiredoxine were presented by M. Baier (Bielefeld, Germany). An important result of this study was the characterization of a redox-sensitive domain within the promoter of the 2CPA gene. This element of the promoter is presently used for the identification of a transcription activator linking the signals from chloroplasts, abiotic stress, and metabolic status of the cell. T. Pfannschmidt (Jena, Germany) covered the current notions about redox-regulated signaling pathways of short-term and long-term responses related to light adaptation. The speaker showed that long-term responses to light spectral changes depended on stoichiometric adjustment of photosystem involving redox signals from the electron transport chain of photosynthesis. Thus, redox signals of the chloroplasts are a novel class of plastid signals, and their discovery at last made it possible to reconstruct the relationships between redox signaling and plastid signaling.

Concerning the signal transduction from the chloroplast to the nucleus, D. Leister (Munich, Germany) paid special attention to the influence of post-translation modification and translation activity in the organelles on the transfer of information from the chloroplasts to the nucleus. Although some new results were obtained by means of mutant analysis, the nature of signals and the way of their transduction to the nucleus remain so far unknown.

A. Raghavendra (Hyderabad, India) reviewed current ideas of the interaction of metabolic reactions in various plant cell organelles. New findings concerning the regulation of glutathione biosynthesis in plants were presented by M. Hothorn (Heidelberg, Germany). The report by F. Rolland (Leuven, Belgium) dealt with