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# Preface

## *Oxygen metabolism coming up ROSes: a holistic view of the redox metabolism of plant cells*

A holistic approach to the oxygen metabolism of plant cells requires consideration not only of the underpinning chemistry and of the factors that contribute to and control the production of active forms of oxygen, but also how cells perceive and respond to changes in the abundance of Reactive Oxygen Species (ROS). Formed during the reduction of molecular oxygen or water oxidation, ROS are produced by a variety of enzymes and redox reactions in almost every compartment of the plant cell. However, the accumulation of ROS in any tissue or cellular compartment is tightly controlled by the endogenous antioxidant systems that limit the lifetime of the ROS signal, maintaining an appropriate balance between generation and removal that determines the nature of the response. Furthermore, ROS interact with reactive nitrogen species (RNS) such as NO in an intricate network of reciprocal control modulating gene expression and cell fate. The papers comprising this Special Issue arise from presentations given at the meeting of the Plant Oxygen Group of the Society for Free Radical Research (Europe) that was held at the University of the West of England, Bristol in December 2005. In this forum, new findings concerning the essential themes of the redox network were presented and discussed. The meeting which was titled *Oxygen Metabolism, ROS and Redox Signalling in Plants* addressed recent developments and current concepts in this important area of plant science, demonstrating that ROS and redox signalling impinge on a wide range of plant cell activities.

Issues discussed included how ROS are produced, how production and accumulation are regulated, and how some of the different components influence the status of the reductant/antioxidant/oxidant continuum that spans reactive oxygen and compounds such as thiols, haem groups, nitric oxide, ascorbate, tocopherol, and secondary metabolites. A number of contributions presented in this Special Issue consider each of these in detail. Underpinning bioenergetics involve the pyridine nucleotides, NAD and NADP, which participate in hundreds of redox reactions in living cells, as emphasized by Noctor *et al.*, who discuss the pathways by which these co-factors are synthesized and their potential significance in plant stress responses. Among the key roles of pyridine nucleotides is the regeneration of ascorbate and glutathione. Bartoli *et al.* discuss the role of ascorbate regeneration pathways and the co-ordinated effects of light and respiration on ascorbate synthesis and accumulation in the model plant *Arabidopsis*, while Kärkönen and Fry report the results of investigations into the effects of ascorbate degradation on hydrogen peroxide production. Ascorbate-deficient *Arabidopsis* mutants have been particularly important in the elucidation of the synthesis and functions of ascorbate in plants. The role of ascorbate on plant growth and development in two of these mutants, *vtc1* and *vtc2*, is discussed by Olmos *et al.*, while Barth *et al.* consider the effects of ascorbate on flowering and senescence. This theme is continued by Locato *et al.*, who have investigated the role of ascorbate in programmed cell death showing that modulation of the *top1β* gene induced cell death influences tissue ascorbate levels. The functions of other important antioxidants are also considered in detail. For example, Krieger-Liszkay and Trebst discuss the role of tocopherol as a scavenger of singlet oxygen produced by photosystem II. Although relatively little attention to date has focused on the regulation of protein thiol disulphide exchange in ROS-linked reactions, Rouhier *et al.* discuss the importance of glutaredoxin systems in plants while Dietz *et al.* consider the crucial role of peroxiredoxins as ROS sensors. The roles of different proteins in ROS perception is reviewed by Hancock *et al.*

It is now widely accepted that ROS have diverse roles in many aspects of plant physiology and development. While the earliest studies considered ROS only as destructive metabolites, later studies showed that they have diverse roles in protecting plants against invading pathogens and environmental stress. Through redox-modulation of proteins and other bio-molecules, ROS participate in the control of many of the activities of the plant cell. Recent evidence has shown that ROS functions are far more wide-ranging than originally thought, as they participate in the regulation of gene expression and act as second messengers in hormone signalling cascades. Moreover, each form of active oxygen and each antioxidant appears to regulate discrete sets of genes. For example, singlet oxygen modulates sets of genes that are distinct from those regulated by superoxide and hydrogen peroxide. Laloi *et al.* describe the use of genetics to unravel such interacting ROS signalling pathways in *Arabidopsis* showing that singlet oxygen and superoxide may act antagonistically to control genetically programmed cell suicide events. Flors *et al.* have used a new fluorescence sensor for singlet

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oxygen, which may open the way to further work in this difficult field, and help a future understanding of the production and role of this poorly studied ROS.

The marked increase in cellular oxidation that occurs during the senescence process in pea leaves is documented by Vanacker *et al*., while Palma *et al*. discuss the intracellular localization of antioxidant enzymes in this context. Similarly, Veljovic-Jovanovic *et al*. consider the role of antioxidants during senescence induced by drought. In addition to the above, the RNS interaction is discussed by Pauly *et al*. in the context of legume–microbe interactions. Nitric oxide may lead to the nitrosylation of proteins, as considered by Wang *et al*. and to the modulation of peptides such as glutathione in cadmium stress as introduced by Barroso *et al*.

Interestingly, Mateo *et al*. report a relationship between the abundance of salicylic acid and the efficiency of photosynthesis. Other authors focus on more specific systems: for instance photoinhibition of photosystem II is described by Hakala *et al*. while Davies *et al*. discuss some new findings in plant/pathogen responses. Other developmental programmes such as root hair formation also involve ROS signals as discussed by Carol and Dolan. A further example is plant reproduction which involves a ROS-producing specific peroxidase in the stigma, as outlined by McInnis *et al*.

Taken together, these articles reflect the explosion of interest and considerable progress that has been made in this dynamic field to date. It will be intriguing to see how future work on oxygen metabolism will diversify as, while undoubtedly continued emphasis will be placed on the central role of ROS and antioxidants, these articles should provoke new ideas concerning how other molecules participate in redox signalling in plants.

John T. Hancock
Nick Smirnoff
Christine H. Foyer