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Hydrogen Peroxide and Plant Stress: A Challenging Relationship

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ABSTRACT

The relationship between plants and hydrogen peroxide is a challenging one: H_2O_2 has many essential roles in plant metabolism but at the same time, accumulation related to virtually any environmental stress is potentially damaging. In this review, I consider H_2O_2 physiology broadly, both as a stress and as a developmentally and physiologically important metabolite, including its sources and mobility, and the vexing question of tissue level concentrations. I then consider problems associated with H_2O_2 as a signaling molecule, including mechanisms of H_2O_2 sensing, signaling, and response networks. Finally, I discuss recent advances in transcript network modeling, and complex systems approaches to understanding the interactions between the transcriptome, proteome and metabolome in responses to H_2O_2.

Keywords: amine oxidase, apoplast, complex systems modeling, NAD(P)H oxidase, peroxidase, transcriptome, photosynthesis, proteome, mitochondria, signaling cascade

Abbreviations: APX, ascorbate peroxidase; **CAT**, catalase; **DAO**, diamine oxidase; **GLP**, germin-like protein; **HR**, hypersensitive response; **MAO**, monoamine oxidase; **MAPK**, mitogen-activated protein kinase; **PAO**, polyamine oxidase; **POX**, peroxidase; **ROS**, radical oxygen species; **SOD**, superoxide dismutase

CONTENTS

INTRODUCTION

It is now well established that virtually all biotic and abiotic stresses induce or involve oxidative stress to some degree, and the ability of plants to control oxidant levels is highly correlated with stress tolerance. Whether the antioxidant approach to explaining tolerance will, in the long run, be any better as a single factor explanation than, say, the ability to exclude Na from shoots and maintenance of K/Na discrimination ratios has been for salt tolerance, or the ability to accumulate compatible osmotica has been for drought tolerance, remains to be seen. It is now clear, however, that any stress condition or significant change in environment is associated with up- or down-regulation of hundreds of genes, that some proteins important to oxidative metabolism may have high stabilities and low turnover rates, and that even the cell wall, once considered of little biological importance, contains hundreds of proteins and metabolites, many of which may be involved in oxidative metabolism.

At the same time, it is also well established that oxidative metabolism, and particularly H_2O_2, is involved in a wide variety of reactions and signaling cascades necessary for all aspects of plant growth and the integration of activity, ranging from the develop of individual root hairs, to xylem differentiation and lignification, to wall loosening and wall cross-linking, to root/shoot coordination and stomatal control. Thus, while the involvement of H_2O_2 in stress responses is of particular interest, it really must be considered in the context of, and even as a special case of, H_2O_2 involvement in "normal" growth and metabolism.

Overall, the current "fashion" in plant stress studies is to grow plants in controlled conditions, apply a stress rather suddenly after a period of unstressed growth, and then compare some aspect or aspects of response – ranging from activity of a single enzyme to whole genome transcript networks – at a fixed time thereafter. Unfortunately for plant biologists, but fortunately for plants, such environmental

Received: 6 March, 2007. Accepted: 30 April, 2007.