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BAKER SCIENTIFIC APPLICATION BULLETIN

Oxygen Counts in Depth - Plants Respond to Flooding

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Why low oxygen study conditions make a difference

Plant, oxygen, flooding, submergence, adaptation, crop loss, aquaporins

CONTENT

Plant cells need oxygen for mitochondrial aerobic respiration in order to produce energy. Especially dense, bulky or metabolically active tissues (fruits, seeds, meristem and phloem) often face oxygen deficiency even when external oxygen is available. In water the diffusion of oxygen is about 10,000 times lower than in air (depending on water temperature) so plants exposed to flooding and soil compaction commonly face oxygen deprivation. Conducting experiments in biologically relevant O_2 levels is a key element in studying plant physiology in general and flooding resistance, an issue of major agricultural and economic importance, in particular.

Diversity and distribution of plant species in natural ecosystems are increasingly affected by flooding, which can also lead to massive losses of farmland crops. Soybean, maize, wheat and rice, the four major crops are all highly sensitive to submergence whereas rice has adapted well to soil waterlogging (Bailey-Serres et al 2012). Understanding and utilizing the underlying adaptive mechanisms is thus of both scientific and economic interest.

Plants growing in oxygen-deprived conditions, either severe anaerobic or low oxygen ethylene-driven underwater growth, face energy and carbohydrate stress that is controlled by regulating carbohydrate and energy reserves. Inundation of aerial organs drastically reduce gas diffusion rates compromising respiration at the level of electron transport. Lack of O_2 as an electron acceptor leads to a saturated redox chain reaction, accumulated NADPH, and decreased ATP production (Kennedy et al 1992). Two broad strategies for survival of submerged shoots are demonstrated: elongation of the shoots for escaping above the flood, or to become quiescent and preserve energy supplies. Lack of oxygen also inhibits roots from transporting water as well as facilitating stomatal closure. The inhibition of the root hydraulic conductivity system under scarce oxygen is due to changes in root morphology and the function of aquaporins (AQPs). AQPs are membrane proteins that respond to environmental stress factors exerted on the plant, including lowered O_2 tension. They transport water, small neutral solutes, as well as ions. Plants respond to conditions like flooding or drought by closing AQPs. The signals for gating water pores include changes in environmental pH, phosphorylation, and intracellular Ca2+, all of which can be linked to O_2 deprivation.

Another stress occurs when floodwater retreats and low O_2 -acclimatized plants again encounter normal terrestrial conditions. The receding water has been proposed to, in combination with increasing the level of illumination exposure, trigger a rapid production of reactive oxygen species (ROS) which in turn induces oxidative stress (Biemelt et al 1998).

What then is known of the adaptive mechanisms and the sensing mechanisms that underly them? The low-O_2 stress, energy homeostasis and energy usage of rice seeds germinated under water are connected by a calcineurin B-like interacting kinase (CIPK) and are regulated by DNA binding proteins acting downstream of ethylene modulating gibberellin. In O_2-deprived plants, the gene expression of AQPs is modified, probably contributing to plant hypoxia tolerance (Tan X et a 2018). In two oak species (Quercus petraea and Quercus robur), transcriptional profiling has identified three genes to be differentially regulated by hypoxic stress (PIP1;3, TIP2;1 and TIP2;2; Rasheed-Depardieu et al 2015) showing that the responses are not only very complex but also species specific. In Arabidopsis thaliana, a specific oxygen-sensing mechanism underlying some of these responses has been identified (Licausi et al 2011).A conserved amino-terminal amino acid sequence of the ethylene response factor (ERF)-transcription factor RAP2.12 can be dedicated to an oxygen-dependent sequence of post-translational modifications, which ultimately leads to degradation of RAP2.12 via the ubiquitin-dependent N-end rule pathway for protein degradation under aerobic conditions. When the oxygen concentration is low—as during flooding—RAP2.12 is released from the plasma membrane and accumulates in the nucleus to activate gene expression for hypoxia acclimation.

Submergence tolerance and fertility has been shown to be linked to the rate of submergence recovery in specific Arabidopsis thaliana ecotypes Bay-0 and Lp2-6. By assessing the ribosome-associated transcripts it has been shown that the differential recovery relates to the activity of three genes: RESPIRATORY BURST OXIDASE HOMOLOG D, SENESCENCE-ASSOCIATED GENE113, and ORESARA1. The latter functions in a regulatory module involving a ROS burst upon desubmergence and the hormones abscisic acid and ethylene. The module controls ROS homeostasis, stomatal aperture, and chlorophyll degradation during submergence recovery (Yeung et al 2018).

Even with the increased understanding of plant signaling dynamics during flooding relatively little is known about for instance electrophysiological changes acutely followed by hypoxia. Similarly, the temporal dynamics of flooding signals and the regulatory loops they create need to be better understood in order to understand the relevance of each response to plant survival.

| TOOL TIPS

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- Seeds
- Roots development
- Aerenchyma development
- Shoot elongation
- Transcriptomic and metabolic reconfiguration
- Energy metabolism
- Cytosolic pH
- ROS formation
- Ethylene responsive factor (ERF) transcription factor genes
- Gibberellin acid
- SUB1A, SUB1B and SUB1C
- SNORKEL1 (SK1) and SNORKEL2 (SK2)
- HRE1, HRE2, RAP2.2 or RAP2.12
- RESPIRATORY BURST OXIDASE HOMOLOG D
- SENESCENCE-ASSOCIATED GENE113
- ORESARA1

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