GÖTEBORGS UNIVERSITET

INSTITUTIONEN FÖR BIOLOGI OCH MILJÖVETENSKAP

Role of mycorrhiza symbiosis and phosphorus nutrition in plant growth, photosynthesis and secondary metabolism

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Akademisk avhandling för filosofie doktorsexamen i naturvetenskap, inriktning biologi, som med tillstånd från Naturvetenskapliga fakulteten kommer att offentligt försvaras fredagen den 21 oktober 2016 kl. 10.00 i Hörsalen, institutionen för biologi och miljövetenskap, Carl Skottbergs gata 22B, Göteborg.

ISBN: 978-91-85529-95-7 (Tryckt)
ISBN: 978-91-85529-96-4 (PDF)
Tillgänglig via http://handle.net/2077/45912

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Abstract

Inorganic phosphorus (P_i) is an important and often limiting nutrient for plants. Large amounts of P_i fertilizers derived from non-renewable rock phosphorus, are used in agriculture. These are applied in excess but crops take up only a small amount of P_i; the residual P_i ends up in water systems where it causes problems with eutrophication. Plants can increase their P_i uptake efficiency by forming a symbiotic association between their roots and arbuscular mycorrhizal (AM) fungi. During symbiosis, AM fungi provide the host with P_i in return for carbohydrates synthesized in the leaf chloroplast through photosynthetic assimilation of CO_2. For AM symbiosis to be a plausible tool in modern agriculture, the symbiotic interaction needs to be optimized for generating a positive growth response of the crop. To achieve this, knowledge about the signaling between the plant and the fungus is crucial. It is known that both P_i signalling and AM symbiosis are tightly connected to metabolic processes in the chloroplast. In response to P_i limitation, more sugars and starch accumulate in leaves, and transport of sucrose towards roots increases. AM symbiosis increases the flow of sucrose towards the root system and induces production of secondary metabolites, which is initiated in the chloroplast.

An *Arabidopsis thaliana* mutant lacking the chloroplast-localized P_i transporter PHT4;1, was studied in **Paper I** to get a deeper understanding about the role of P_i supply in the chloroplast. The mutant displayed a reduced activity of the chloroplast ATP synthase due to P_i limitation, which resulted in less CO_2 assimilation, decreased levels of sugars in the shoot, reduced leaf size and biomass. The influence of AM symbiosis and P_i fertilization on growth and chloroplast processes such as photosynthesis and secondary metabolism was studied in *Medicago truncatula*. In **Paper II,** it is shown that AM symbiosis and P_i fertilization stimulate the expansion of shoot branches and leaves, whereas AM symbiosis specifically increases the number of chloroplasts. The increased surface area of the shoot enables the plant to harvest more sunlight. These morphological alterations are attributed to an enhanced level of cytokinins in leaves of AM- and P_i-treated plants (**Paper III).** In **Paper III,** it is also shown that AM symbiosis and P_i fertilization induce largely different transcriptional and metabolic responses. AM-specific responses were increased expression of secondary metabolite genes, and enhanced production of flavonoids and the hormone abscisic acid (ABA).

In conclusion, a model is proposed where a long distance signal in mycorrhized roots, derived from the enhanced carbon demand of the fungus, affects production of secondary metabolites in leaf chloroplasts. Validating this model will help to better understand the signaling between the plant and the fungus during AM symbiosis. This will allow the development of systems where AM symbiosis is used in agriculture for more efficient Pi uptake by crop plants.

ISBN: 978-91-85529-95-7