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DOCTORAL DISSERTATION ABSTRACT

Scientific discipline: biological sciences

Title of the doctoral dissertation: "Assessment of the usefulness of poly-γ-glutamic acid (γ-PGA) in mitigating the effects of soil drought in yellow lupine (*Lupinus luteus* L.) roots"

Doctoral dissertation abstract: The reduced yield of yellow lupine (*Lupinus luteus* L.) results from its high sensitivity to drought stress, which disrupts root system functioning and nodule activity, thereby decreasing atmospheric nitrogen fixation. One environmentally friendly approach to limiting the negative effects of water deficit in plants is the use of biostimulants. This study aimed to evaluate the potential of one such stimulant, the biodegradable polymer poly-γ-glutamic acid (γ-PGA), to alleviate drought effects in the roots of L. luteus. It was demonstrated that this compound exerts effects that depend on dose, time of application, and stress duration. Plants treated with γ-PGA at the onset of water deficit concentrate their resources on protecting basic metabolism, postponing the energy-demanding symbiosis. At the early stage of drought, the polymer stabilizes the photosynthetic apparatus, improves tissue turgor, and stimulates plant growth, whereas maintaining symbiotic interactions requires its application at a later stress phase. Irrespective of the duration of plant exposure to drought, γ-PGA normalizes osmotic homeostasis, reducing the need for proline accumulation. In addition, it selectively activates antioxidant defense mechanisms, avoiding costly and uncontrolled induction of the entire system. The polymer counteracts the drought-induced increase in guaiacol peroxidase activity while enabling hydrogen peroxide detoxification mainly via ascorbate peroxidase, thereby alleviating oxidative stress and reducing lipid peroxidation. The polymer also induces remodeling of cell wall metabolism associated with the presence of low- and high methylesterified pectins, arabinans and galactans, xyloglucans and xylogalacturonans, reversing drought-induced changes. This minimizes damage and preserves the structural integrity of nodule cells, particularly in the nitrogen fixation zone, which promotes the maintenance of symbiosis under

dehydration. These observations are supported by microscopic analyses of nodule tissue and cellular structure, in which no drought-induced degenerative changes were detected after γ-PGA treatment. The polymer sustains the physiological functionality of these structures, as evidenced by the reversal of the negative impact of stress on the expression of genes crucial for nodule functioning (LlBOP and LlLbL). Application of γ-PGA under drought conditions suppresses excessive activation of stress phytohormone biosynthetic pathways by modulating the expression of their biosynthesis genes (LlACS, LlACO, LlZEP, LlLOX), which results in altered tissue distribution of the ethylene precursor, abscisic acid, and jasmonic acid. Modification of the distribution of fatty acid amide hydrolase, involved in the catabolism of lipid signaling mediators, in response to γ-PGA indicates the activation of adaptive 14 mechanisms of lipid homeostasis. At the proteomic level, γ-PGA enhances antioxidant systems, modulates amino acid metabolism, and increases the synthesis of protective compounds, while simultaneously preserving symbiosis and basic metabolic processes. In summary, by acting at multiple levels through the regulation of redox, phytohormonal, and lipid homeostasis, as well as cell wall remodeling, γ-PGA stabilizes root cell metabolism and enhances the drought tolerance of L. luteus.

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doctoral student's signature