Streszczenie rozprawy doktorskiej w języku angielskim

Leguminous plants, including narrow-leafed lupine, are gaining popularity due to their potential to form symbiotic relationships with soil bacteria, which through the process of Biological Nitrogen Fixation (BNF), convert atmospheric nitrogen into forms biologically available to plants. This property significantly reduces the need for expensive synthetic fertilizers and enriches soils for subsequent crops. In addition to nitrogen fixation, Bradyrhizobia also contribute to plant growth by actively participating in the breakdown of compounds in soil into forms more available to plants. They are also capable of extracellular secretion of secondary metabolites, which may induce plant growth and assist in protection against diseases and abiotic stress.

The establishment of an effective symbiotic relationship between rhizobia and the appropriate macro-symbiont is influenced by various factors. Both plants and free-living microorganisms are exposed to various biotic and abiotic factors that may limit their development, survival, and ability to enter into a symbiotic relationship.

Despite the fact that many heavy metals (HMs) are essential trace elements for the proper functioning of living organisms, at elevated concentrations, they exhibit high toxicity, posing a threat to both bacteria and plants and significantly impacting the symbiotic system. The homeostasis of heavy metal ions is a sensitive balance in which bacterial cells must maintain sufficient levels of metals to ensure the proper functioning of essential enzymes while preventing toxicity caused by their higher concentrations.

Comprehensive studies on the impact of many heavy metals on the molecular mechanisms, phenotypic properties, and metabolic profiles of microsymbionts and macro-symbionts such as *Lupinus angustifolius* have not yet been conducted. Therefore, the subject of the research described in this dissertation was an attempt to understand the mechanisms underlying the interactions of selected heavy metals (copper, nickel, manganese, and cadmium) with free-living bacterial cells of symbiotic bacteria from the genus *Bradyrhizobium* (two strains of *B. japonicum* (UPP 133, UPP 331) and two strains of *B. canariense* (UPP 213, UPP 242)), as well as their impact on the symbiotic relationship between leguminous plants and soil bacteria.

Conducted experiments have shown that heavy metal ions, such as Cu^{2+}, Ni^{2+}, Cd^{2+}, and Mn^{2+}, have a significant impact on the growth of *Bradyrhizobium spp.* cells. High concentrations of these ions inhibit cell growth, with Cd^{2+} ions exhibiting the greatest toxicity to these microorganisms. Furthermore, Cu^{2+}, Ni^{2+}, and Mn^{2+} ions demonstrated the ability to stimulate the synthesis of indole-3-acetic acid (IAA), with the highest production of IAA observed for the strain *B. canariense* UPP 242, at a concentration of 0,5 mM $CuCl_2$, reaching 8.09 g/mL. Conversely, Cd^{2+} ions exhibited inhibitory effects on this process. Cu^{2+} ions at concentrations of 0,5 mM and 1 mM, Ni^{2+} ions at concentrations of 0,5 mM and 1 mM, and Mn^{2+} ions at concentrations of 0,125 mM and 5 mM significantly increased the production of exopolysaccharides (EPS). Additionally, Mn^{2+} ions most strongly stimulated the production of siderophores by strains UPP 133, UPP 213, and UPP 242.

Analyses of the expression of the *treS, cueA, exoR*, and *fegA* genes showed that the selected heavy metals have an impact on the expression levels of these genes, with these changes being time-dependent. Changes in *treS* gene expression were also species-specific. Except for Cu^{2+} ions, whose presence increased gene expression by 170% after 24 hours, all of the studied heavy metal ions had no significant effect on the expression levels of the nodulation factor NodA.

Furthermore, a significant impact of selected heavy metal ions on the germination of narrow-leafed lupine seeds was observed. All of them at low concentrations showed a positive effect on this process, while their higher concentrations led to its slowing down and even necrotic changes.

Impact of seed inoculation with *Bradyrhizobium spp.* strains grown in the presence of Cu^{2+} ions at a concentration of 0,5 mM is showing a significant potential for further research. The root systems developed from these seeds were more aboundant and had a greater mass than those in control trials.

In summary, the research results open up new research possibilities regarding the adaptation of plants and microorganisms to conditions of heavy metal pollution. Understanding these interactions may lead to the development of strategies to improve crop productivity and soil bioremediation methods, ultimately contributing to the development of sustainable agricultural practices and environmental protection.

Wikodem