Title of the dissertation: **Development of an innovative multielemental smart fertilizer formulation based on waste raw materials and with a slow release of nutrients**

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Abstract:

Modern agriculture faces a key challenge: how to increase food production while protecting the environment and ensuring high nutritional value. Traditional, intensive production methods, while meeting the energy needs of the population, lead to soil degradation and food depletion of micronutrients. The problem of "hidden hunger," that is, the scarcity of components such as Zn and Se, affects up to 2 billion people and requires new, systemic solutions.

In response to these challenges, the principles of regenerative agriculture and the circular economy are becoming increasingly important. Biofortification - the enrichment of food with nutrients at the plant growth stage, which is much more effective than traditional supplementation or fortification - is becoming a key element.

One of the most promising approaches is the use of waste raw materials as a source of nutrients. In the face of rising costs and limited availability of mineral raw materials, returning previously lost substances to the production cycle is becoming economically and ecologically viable. However, in order for these nutrients to become available to plants, valorization is often required, in which soil microorganisms play a key role.

Innovative technologies, such as microbial fertilizers in the form of freeze-dried bacteria on solid carriers, allow efficient and controlled release of nutrients. Such smart fertilizers minimize losses, balance soil processes and promote plant growth. The integration of these solutions - waste recycling, use of microorganisms and smart fertilization - provides the foundation for the agriculture of the future, which will provide both abundant and high nutritional quality food, addressing global nutritional challenges.

The aim of the research was to develop an innovative fertilizer formulation based on sewage sludge ash, slaughterhouse waste from the agri-food industry and nutrient solubilizing bacteria to manage waste and improve crop yields and increase Zn and Se content in the crop. The research was conducted in four stages.

In the first stage, a collection of 16 bacteria was collected. Bacteria were subjected to selection, taking into account their resistance to abiotic conditions, ability to solubilize nutrients, produce plant growth-promoting compounds, and compatibility with other bacteria and plants. It was shown that the selected bacteria showed relatively high resistance to elevated Se concentrations, leading to Se reduction, had the ability to solubilize P from tricalcium phosphate, to solubilize Zn from zinc carbonate and to solubilize P from sewage sludge ash. The selected bacteria were capable of producing siderophores, indolyl-3-acetic acid, and ammonia. *Bacillus* and *Pseudomonas* bacteria were compatible and had a good effect on radish germination. The most promising *B. megaterium* and *P. putida* were successfully cryopreserved with sucrose.

In the second stage of the study, the focus was on the selection of waste materials that contained a high amount of nutrients and were susceptible to microbial solubilization. Elemental composition analysis revealed high P, Zn and Se contents in sewage sludge ash and fish meal. Microbial solubilization by the bacteria *P. putida* and *B. megaterium* showed that the ash and fish meal released significant amounts of dissolved P, Zn, and there was a reduction in the concentration of dissolved Se. On this basis, ash and fish meal were selected as the main raw materials for fertilizer formulation development. The pH decrease, acid phosphatase activity and oxidizing conditions were responsible for solubilization.

In the third stage of the research, granular fertilizers were developed. A series of granules with different proportions of ash, fish meal, hemoglobin and sucrose were prepared. The selected granules were characterized by good resistance to compression. "Balanced" mixture of raw materials (20S /10H /25R /45P) was susceptible to liquid and solid microbial solubilization, releasing nutrients under the influence of bacteria, reduced pH, acid phosphatase activity and oxidizing conditions. As a result of optimization of the composition and introduction of freeze-dried bacteria into the granules, an "optimal" fertilizer mixture of 22.71L /15.00H /26.61R /35.68P was obtained. Such a mixture yielded more compression-resistant granules and was susceptible to microbial solubilization, which proceeded stably.

The fourth stage of the study tested the effect of fertilizer on plant growth. Radish seed germination tests showed that the best fertilizer dose was 0.25% m/m. In preliminary 9-day germination tests, the raw material mixture was compared with the control groups, finding favorable effects on soil bacterial viability, acid phosphatase activity, as well as growth parameters and increased P and Zn content in radish sprouts. In radish yield studies, an increase in the fresh and dry weight of the hypocotyl was found, as well as an increase in the content of P, Zn and Se, proving the effectiveness of the developed fertilizer in improving plant yields and their biofortification. This was confirmed in leek, onion, tomato and bell pepper crops, for which higher yield weight and increases in P and Zn content were also obtained.

As a result of the research, a novel granular fertilizer based on waste materials rich in nutrients and bacteria that increase their availability was developed, which effectively improves plant yield and increases nutrient content. The use of bacteria promotes organic fertilization and food biofortification. Innovative technology using waste can reduce the need for artificial fertilizers. This approach has the potential to improve food quality, protect the environment and public health, which is an important step toward more sustainable and efficient agriculture.

Research into the development of an innovative fertilizer represents an important step towards sustainable agriculture, as it allows for the transformation of difficult-to-manage waste into a valuable product. This innovative approach, which uses microorganisms to improve soil quality and enhance crop yields, aligns with the principles of regenerative agriculture, and the resulting fertilizer has the potential for commercialization.