Technology for manufacturing granular mineral fertilizers with a bioactive polymer coating containing lyophilized spore-forming bacteria

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Modern agriculture must simultaneously maintain high crop productivity and reduce the environmental burden associated with conventional mineral fertilization. Solutions that improve nitrogen and phosphorus use efficiency, reduce nutrient losses to the environment, and enhance plant tolerance to drought stress are of particular importance (Lesueur et al., 2016). Mineral fertilizers enriched with beneficial microorganisms are a promising approach, but their broader implementation is often limited by poor microbial stability during manufacturing and storage, as well as by the use of water-based processing followed by drying at elevated temperature.

The aim of this work was to develop a technology for manufacturing a granular mineral fertilizer with an external coating containing biologically active agents, while eliminating water from the microbial application step and minimizing process factors that reduce microbial survival. The technological concept was based on physically separating the microorganisms from the mineral fertilizer core by means of a readily soluble polymer coating that remains neutral toward both the fertilizer and the biological preparation.

The developed product is a biofertilizer in the form of mineral fertilizer granules coated with a layer accounting for 2–20% of the product mass and containing polyethylene oxide as a binder, optionally combined with glycerol, and, if required, one or more auxiliary substances from the group of saccharides or sugar alcohols in an amount of 0–50% of the coating mass. The bioactive agents are lyophilized preparations containing spore forms of bacteria, especially of the genera Bacillus or Paenibacillus. The novelty of the proposed approach lies in the use of a low-melting polymer binder and a dry or liquefied coating system applied to heated fertilizer granules without water, thereby limiting spore activation and subsequent cell death during drying and storage.

In the developed process, mineral fertilizer granules, especially NPK, phosphorus-calcium, or nitrogen-magnesium-sulfur fertilizers, were heated to 70–90°C and then coated in a pan granulator or drum granulator with powdered or liquefied polyethylene oxide, optional additives, and the microbiological preparation. After coating formation, the product was cooled below 40°C and classified by particle size, while undersize and milled oversize fractions were recycled back to the process. In the liquid variant, the polymer was liquefied by heating and sprayed onto the fertilizer, whereas the microbiological component was added separately.[

The experimental results confirmed that a uniform, readily water-soluble coating could be formed on mineral fertilizer granules for several fertilizer formulations. The research demonstrated the feasibility of the method for NPK, phosphorus-calcium, nitrogen-magnesium-sulfur, and NPKMgS fertilizers, with coating thicknesses of approximately 0.1–0.2 mm and coating contents typically in the range of 5–10 wt%. The coating composition included PEG as the binder and sucrose, maltodextrin, or glucose as auxiliary ingredients, together with lyophilized Bacillus preparations.

Microbiological testing showed microbial survival above 95% during production, while the loss of viable microorganisms during storage did not exceed 20% after one month. Depending on the process variant, the final products contained approximately 1.9 × 10^6 to 9.5 × 10^6 CFU per gram of fertilizer. These findings indicate that eliminating water and limiting microbial exposure to moisture, high pressure, and aggressive local salt concentrations can preserve high biological activity in the final product.

An important part of the study was the evaluation of how binder composition affected the physical properties of the coated granules. The addition of glycerol to PEG improved coating uniformity, reduced surface roughness, increased the desirable product fraction from 94% to 96%, and lowered the undersize fraction before classification from 5 to 3 wt%. This result confirms that coating formulation affects not only microbiological stability but also the technological quality of the fertilizer product.

The developed formulations were also assessed with respect to their biological effects in soil and their impact on crop performance. Soil biodiversity studies based on DNA analysis confirmed an increase in the population of viable bacteria used in the biofertilizer after application. Agricultural trials performed on maize and wheat showed beneficial effects on plant growth and yield compared with mineral-fertilized control treatments without bacterial addition, resulting in statistically significant yield increases in the first year of testing.

A particularly important observation was the stimulation of root system development in plants treated with the coated biofertilizers. This effect may be highly relevant under water-limited conditions because a better-developed root system improves water and nutrient uptake and may enhance plant tolerance to drought stress. From an agronomic perspective, the proposed solution therefore combines a fertilizing function with a biological plant-growth-supporting effect.

The significance of the reported research lies in combining several features that are rarely achieved simultaneously in current biofertilizer technologies: high microbial survival, process simplicity, elimination of water and final drying, and the possibility of continuous operation with recirculation of off-size fractions. The developed technology does not require expensive high-pressure equipment, does not generate process waste, and can be adapted to different types of mineral fertilizers. It therefore represents a meaningful contribution to the development of next-generation functional fertilizers for more sustainable crop production systems

References

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