



Phosphate Sources, Microorganisms, and P Plant Nutrition: Challenges and Future Trends

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Abstract

This mini-review deals with P-plant nutrition starting from the crude P-source, its further processing, most recent alternative P-sources, and biotechnological solutions of existing problems. Special attention is given to microbial P solubilization in fermentation systems as an alternative of chemical P-fertilizer production. Another emphasis of the mini-review is on the biofertilizer production and formulation.

Introduction

Phosphorus (P) is one of the major nutrients limiting plant growth. Although P is quite abundant in many soils, it is added to soil-plant systems in the form of phosphate fertilizers. Although plants utilize a fraction (normally 12%) of soluble P, a great part of the added fertilizer forms Fe, Al, and Ca complexes [1]. This process determines the need of frequent application of soluble forms of inorganic P [2]. On the other hand, the capacity of soil to bind soluble P is limited, soils receive P in excess of crop requirements, and a great part of chemically produced P fertilizers contaminate the groundwater causing eutrophication of natural water reservoirs [3]. On the other hand, there are serious concerns regarding the phosphate world reserves and the need of new agro- and bio-strategies to face the increasing world human population. Therefore, P-plant nutrition sources of P and P fertilizer production are in the focus of many scientific groups trying to solve the above challenges.

Current P Fertilizer Production

Traditional P fertilizer production is based on **chemical processing** of insoluble mineral high-grade rock phosphate-what in fact is calcium phosphate combined with quartz, calcite, dolomite, clay, iron oxide, carbonates, and alkali compounds. In mined phosphate rocks, phosphate content can range from over 40% to below 5%. This inorganic mineral is further treated to separate the impurities thus improving the quality of phosphate, which after energy intensive chemical treatments (with sulfuric acid at high temperature) ranges from 26% to about 34% [4]. This process generates contaminants into the main product,

gas streams and by-products [5]. Therefore, during the last 10-15 years, scientists working in this field focused their studies in two main directions:

- A) Changing the traditional rock phosphate chemical dissolution scheme and finding alternative sources of P;
- B) Preparation of formulated biofertilizers with P-solubilizing activity.

Biotechnological Approach in Solving Existing P-Production Problems

One of the alternative technologies of rock phosphate dissolution is the application of **biotechnological methods** based on microorganisms [6]. Organic acid producing microorganisms are able to solubilize Al-, Fe-, and Ca-phosphates forming calcium salts of the organic acids and releasing plant available phosphate [7]. This process can be carried out in fermentation and in soil-plant systems. In the first case, it can be carried out in conditions of submerged fermentation or in solid-state fermentation processes [8].

Submerged liquid fermentations can be performed with

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freely suspended or immobilized cells [8]. The main process parameters, which affect the overall productivity of **free microbial cells**, are the initial pH, temperature, agitation and aeration. Medium composition is important as high organic acid production depends on limitation by some macro-elements. Additional components of the fermentation medium such as biochar can significantly enhance the solubilization efficiency [9]. The advantages of **immobilized microbial producers** of organic acids have been repeatedly demonstrated [10] but confirmed again in the presence of insoluble phosphates [11]. This approach is very efficient particularly in case of liquid biofertilizer production [12] as immobilized cells can be efficiently used in repeated-batch or continuous mode of fermentation.

Solid-state fermentation is another useful biotechnological tool for inorganic phosphate solubilization [13]. This mode of fermentation processes makes use of solid substrates, mainly agro-industrial wastes, and during the last years is widely used in the production of biofertilizers and biocontrol agents [14]. The main process parameters are the age and volume of inoculum, initial pH, temperature, moisture level, and need of aeration or substrate mixture. Optimization of the solid-state fermentation process can enhance the solubilization of rock phosphate thus improving the effect of the final, formulated product on plant growth [15]. In general solid-state fermentation is characterized by a number of advantages such as improved product characteristics, higher productivity and yields, easier downstream operations and product recovery, and reduced energy process requirements [16]. Particularly in the field of biofertilizers and P-solubilizers, this mode of fermentation offers a high number of spores for further formulation or a mixture of partly mineralized organic matter, microbial biomass and solubilized phosphate for direct application [17].

Alternative P Sources

The most studied alternative sources of P are biochar's of vegetal and animal origin. In the first case, soil can be enriched with the soluble P fraction of biochar applied directly in soil. Biochar is an excellent approach to recycle P entrapped in agricultural residues although the P is in insoluble form [18]. Similarly, animal-derived biochar is accepted as a phosphate rich hydroxyapatite, free of the typical contaminants found in rock phosphates [19]. In both cases, soils amended by biochar should be enriched with P-solubilizing microorganisms to convert the insoluble form of P to plant available soluble phosphate. Therefore, we should be able to produce and formulate P-solubilizing biofertilizers.

P-Solubilizing Biofertilizer Production

By definition, biofertilizers are formulated products containing one or more microorganisms that enhance the nutrient status (the growth and yield) and health of the plants by either replacing soil nutrients and/or by making nutrients more available to plants and/or by increasing plant access to nutrients or by producing specific metabolites [20]. P-solubilizing biofertilizers like all other plant beneficial microbial inoculum products are produced by fermentation and further

formulated in liquid or solid forms. Recently, encapsulated cells or spores of P-solubilizing biofertilizers are gaining more interest because of the possibility of formulating more than one microorganism and additionally introduce in the formulation matrix other plant beneficial substances [21].

Conclusion

In conclusion, we should note the great biotechnology progress in phosphate producing technologies developed to substitute for the chemical rock phosphate processing and, in the same time, serious success in formulation of P-solubilizing biofertilizers able to help P-plant nutrition in soil.

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