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Phosphorus Solubilizing Microbes: Propitious Strategy For Biofertilization

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Abstract

Phosphorus (P) is crucial for plant growth and development, it is a macroelement that is required for plants to function physiologically. Even though there are a lot of P-containing organic and inorganic molecules in soil, most of them are inert, making them unavailable to plants. Phosphorus (P) deficiency is widely acknowledged as a critical constraining factor in agricultural production, primarily due to its essential role in various biochemical pathways, including ATP synthesis, nucleic acid formation, and energy transfer processes within plant cells. In rhizosphere soil a diverse community of plant-growth-promoting rhizobacteria (PGPR), particularly phosphate-solubilizing bacteria (PSB) are present, by increasing nutrient bioavailability—especially in the case of phosphate—these bacteria have a beneficial effect on plant growth, increasing total plant productivity and yield. Phosphate-solubilizing microorganisms (PSMs) aid in the hydrolysis of resistant organic and inorganic phosphate (P) forms into soluble forms that are easily absorbed by plants.

Despite decades of research on PSMs, the practical implementation of PSM-based strategies to enhance soil phosphorus fixation and improve crop yields at the field scale remains largely undeveloped. This review aims to deepen our comprehension of the pivotal role played by PSMs as biofertilizers in the context of crop production.

Keywords: - Phosphate(P), PSM, Phosphate solubilization, biofertilizer.

Introduction

Phosphorus being the second most important plant macronutrient has significant role in plant metabolism. Although 98% of Indian soils have lower P availability (Zhang et al.,2000). The total p content in soil is about 0.05% (by weight), of which only 0.1% of the total soil content is available for plants to absorb (Behera et al.,2017). As a result, enormous phosphate fertilizers have been used throughout the past century to maximize plant yields. But a large portion of the phosphate fertilizer is unavailable to plants because high concentrations of P rapidly immobilize and turn insoluble. The biogeochemical cycle of phosphorus depends on phosphate solubilizing bacteria (PSB) in both terrestrial and aquatic environments (Das,S et al 2007). PSM are essential microorganisms that augment the biological availability of phosphorus bound to soil for the plants. By producing organic acids that lower pH and using acid phosphatase enzymes to catalyse mineralization, they aid in the conversion of insoluble phosphorus into soluble compounds. The pivotal involvement of 2-keto-gluconic acid, derived from PSB-mediated glucose oxidation, substantially influences the processes of phosphate weathering and solubilization within the soil matrix. PSBs find extensive utility in agriculture, where they contribute to sustainable methodologies by enhancing soil fertility and mitigating the necessity for synthetic phosphate fertilizers (Karpagam and Nagalakshmi,2014).

Phosphorus accessibility in the soil

Soil contains both insoluble organic and inorganic forms of Phosphorus, follows a "sedimentary" biospheric cycle without atmospheric exchange (Walpola et al.,2012). Unlike nitrogen, phosphorus lacks a significant atmospheric source for organisms, leading to limited crop growth. Soil contains around 0.05% phosphorus, mainly as insoluble phosphates (Satyaprakash et al.,2017). Soluble P varies from ppb in poor soils to 1 mg/L in fertilized ones. Plants uptake $H2PO4^{-}$ or HPO_4^{2-} on the basis soil pH; pH 6-7 is optimal. Agriculture relies on inorganic P, 70-90% converting to inorganic form. Clay-rich soils retain more P due to their extensive surface area. Converting insoluble phosphates to soluble P via processes like PSM could sustain crops for a century, needing a cost-effective solution (Khan AA et al.,2009).

Constraints in using chemical phosphate fertilizers

Over-fertilization is a prevalent concern with phosphate fertilizers. Applying mineral phosphate fertilizers and distributing slurry and manure often surpass the plants' absorption capacity. This results in increased residual phosphorus, particularly in the cultivated areas of the soil. Over time, the soil's dependence on continuous phosphate fertilizer use hinders the shift toward sustainable farming practices. P fertilizers also pose a notable risk of water contamination. Phosphorus introduced to soil through fertilizers, binding tightly to soil particles, tends to remain within the soil. Excessive phosphorus application can lead to water pollution. Plant remnants from phosphorus-rich soils release phosphorus, causing eutrophication. To mitigate this, we use PSMs as biological fertilizers for promoting growth of plants and reduce pollution.

Diversity of Phosphate Solubilizing Microorganisms

PSMs encompass a consortium of advantageous microorganisms that exhibit enzymatic competence in hydrolyzing soil-bound phosphorus compounds into soluble orthophosphates, thereby amplifying their bioaccessibility for plant absorption via root structures. This collective includes bacterial taxa such as *Pseudomonas*, *Bacillus* and *Rhizobium*, as well as fungal counterparts like *Aspergillus and Penicillium*, along with *Actinomycetes* and *Arbuscular mycorrhizal (AM) fungi*. *Microbacterium laevaniformans*, *Pantoea agglomerans* and *Pseudomonas putida* strains are highly efficient insoluble phosphate solubilizers. These microorganisms establish themselves within soil environments, where fertile soils could harbor a diverse bacterial populace, potentially exceeding 2,000 kg ha^{-1} (Timofeeva et al.,2022).

Mechanism of PSM to solubilize inorganic Phosphate

Phosphate-solubilizing microorganisms (PSMs) play a crucial role by producing organic acids that lower soil pH. This acidity transforms stubborn inorganic phosphate compounds into soluble forms. This is vital for various plant functions, including energy production, root development, and cell division. The mechanism involves a complex series of biochemical processes.

1. **Production of Organic Acids:** One of the primary mechanisms employed by PSBs is the production of organic acids, such as citric, gluconic, and oxalic acids (Walpola et al.,2012), (Khan AA et al., 2009). These organic acids are released into the soil by the bacteria and have the ability to lower the pH of the rhizosphere (Khan AA et al.,2009). The acidic environment helps dissolve or chelate the insoluble phosphate compounds, making the phosphate ions more available for uptake by plants. P ions are released through the substitution of H+ or Ca2+ due to the acidic pH, which causes microbial cells and their surroundings to become acidified.

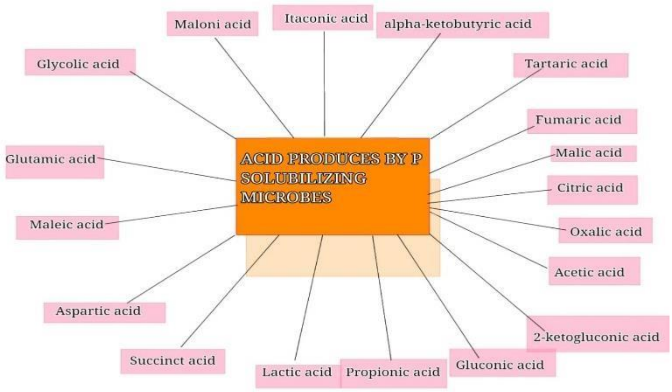

FIGURE 1 – Different organic acids are generated by microorganisms

2. **Chelation and Complexation:** Phosphate solubilizing bacteria (PSBs) rely heavily on chelation and complexation activities. The organic acids synthesized by these bacteria possess the capacity to chelate, forming complexes with metal ions concomitant with insoluble phosphate species (Rodríguez et al.,2007). This chelation event engenders the disruption of chemical bonds existing between phosphate and metal ions, culminating in the liberation of phosphate ions into the soil solution.
3. **Ion Exchange:** Some PSBs possess ion exchange mechanisms on their cell surfaces. These mechanisms involve exchanging nutrient ions (such as hydrogen ions) for phosphate ions bound to soil particles. As a result, the phosphate ions are released from the soil matrix and become available for plant uptake (Selvi et al.,2017).
4. **Phosphatase Enzymes:** Phosphate-solubilizing bacteria often secrete enzymes phosphatases. Phosphatases hydrolyse the organic and inorganic phosphate ester bond and mineral forms of phosphate, respectively. This enzymatic activity releases soluble phosphate into the soil solution, which can then be taken up by plant roots (JC, T,2003).
5. **Mechanical Disruption:** Certain PSMs exhibit the capability to mechanically disrupt the mineral structures housing insoluble phosphate. This phenomenon can be accomplished through the biosynthesis of extracellular polymeric substances (EPS) or other intricate mechanisms that facilitate the degradation of mineral matrices, thereby liberating phosphate ions as an outcome of this process (Aseri et al.,2009).
6. **Mineralization:** In agricultural phosphorus cycling, soil organic phosphorus processes are essential, involving both primary (e.g., apatite, strengite, variscite) and secondary (e.g., Ca, Fe, Al phosphates) phosphate minerals. Phosphatases like phytase hydrolyze organic phosphate, releasing inorganic phosphate for plant uptake. Alkaline and acid phosphatases convert organic phosphate into inorganic forms. Microbes like Soil Bacillus and Streptomyces spp. secrete enzymes such as phosphoesterases, phosphodiesterases, phytases, and phospholipases to facilitate this process. Mixed cultures, including Bacillus, Streptomyces, and Pseudomonas, effectively mineralize organic phosphate (Shen, J. et al.,2011).

Screening and Isolation of PSMs

Plant Growth-Promoting Microorganisms (PSM) are isolated and studied in laboratories using various growth media. Pikovskaya was the first to present a trustworthy preliminary technique for locating and isolating possible PSM (Pikovskaya, R. I,1948). This media contains insoluble tricalcium phosphate (TCP) or hydroxyapatite as the only source of P. Colonies that create a clear halo zone around them on this medium are considered potential PSM after appropriate incubation. The ability of a specific PSM to solubilize phosphate can be quantified using the solubilization index (SI), which is the ratio of the combined diameter of the clearance zone and the colony diameter (Afzal et al.,2008). The formula for calculating the SI is:
SI = (colony diameter + halo zone diameter) / colony diameter.

In another method the change in phosphate fractions in soil can be determined by the following formula: % change in Phosphate = $[(P_2 - P_1) / P_1] \times 100$, where "Final Phosphate Concentration" (P_2) represents the concentration of each fraction (measured in $mg \cdot kg^{-1}$) in the soil after the experiment, and "Initial Phosphate Concentration" (P_1) represents the concentration of each fraction in the soil before the experiment (Kalayu, G.,2019).

Current Adoption and Future Potential of PSMs as Biofertilizers

Because PSMs release organic acids and enzymes that enable plants to access insoluble fixed P molecules in soil, they have a promising future as biofertilizers. It is anticipated that this environmentally friendly substitute for chemical fertilizers will lessen environmental pollution and advance sustainable agriculture (Gyaneshwar et al.,2002). PSMs can also improve soil health, nutrient cycling, and crop productivity while controlling heavy metals. Tailoring PSM technologies to specific geographic regions is essential. Ongoing research aims to enhance PSM strains, application methods, and their integration into agricultural systems. Success depends on factors like strain selection, compatibility with diverse crop types, and local ecological conditions.

Conclusion

Phosphorus is essential for crops, but chemical fertilizers harm the environment and resources are depleting. Soil microorganisms can enhance phosphorus availability. Efficient phosphatesolubilizing microorganisms (PSM) improve crop productivity and soil health. Quality inoculants are vital for success. Research is needed to identify effective PSM for different regions. Soil scientists and microbiologists must find ways to improve soil phosphorus sustainably. Using soil microorganisms to mobilize phosphorus holds promise, but the exact approach is unclear—managing microbes, potent inoculants, genetics, or a mix. Understanding microbe roles is crucial for sustainable agriculture, transitioning from green to evergreen revolution.

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References

1. Z. Zhang, S. Schwartz, L. Wagner, W. Miller. *A greedy algorithm for aligning DNA sequences* J. Comput. Biol., 7 (2000), pp. 203-214
2. B.C. Behera, H. Yadav, S.K. Singh, R.R. Mishra, B.K. Sethi, S.K. Dutta, H.N. Thatoi, Phosphate solubilization and acid phosphatase activity of Serratia sp. isolated from mangrove soil of Mahanadi river delta, Odisha,India,Journal of Genetic Engineering and Biotechnology,Volume 15, Issue 1,2017.
3. Das, S., Lyla, P. S., & Ajmal Khan, S. (2007). Biogeochemical processes in the continental slope of Bay of Bengal: I. Bacterial solubilization of inorganic phosphate. Revista de biología tropical, 55(1), 1-9.
4. Karpagam, T., & Nagalakshmi, P. K. (2014). Isolation and characterization of phosphate solubilizing microbes from agricultural soil. *International Journal of Current Microbiology and Applied Sciences*, *3*(3), 601-614.
5. Walpola, B. C., & Yoon, M. H. (2012). Prospectus of phosphate solubilizing microorganisms and phosphorus availability in agricultural soils: A review. *African Journal of Microbiology Research*, *6*(37), 6600-6605.
6. Satyaprakash, M., Nikitha, T., Reddi, E. U. B., Sadhana, B., & Vani, S. S. (2017). Phosphorous and phosphate solubilising bacteria and their role in plant nutrition. *International Journal of Current Microbiology and Applied Sciences*, *6*(4), 2133-2144.
7. Khan AA, Jilani G, Akhtar MS, Naqvi SMS, Rasheed M. Phosphorus solubilizing b88acteria: occurrence, mechanisms and their role in crop production. *J Agric Biol Sci.* 2009;1(1):48–58.
8. Timofeeva, A., Galyamova, M., & Sedykh, S. (2022). Prospects for using phosphate-solubilizing microorganisms as natural fertilizers in agriculture. *Plants*, *11*(16), 2119.
9. Rodríguez, H., & Fraga, R. (2007). Phosphate solubilizing bacteria and their role in plant growth promotion in Arabidopsis thaliana.
10. Selvi, K. B., Paul, J. J. A., Vijaya, V., & Saraswathi, K. (2017). Analyzing the efficacy of phosphate solubilizing microorganisms by enrichment culture techniques. *Biochemistry and Molecular Biology Journal*, *3*(1), 1-7.

11. JC, T. (2003). Efficiency of some phosphatase producing soil-fungi. *Indian J Microbiol*, *43*, 27-32.
12. Aseri, G. K., Jain, N., & Tarafdar, J. C. (2009). Hydrolysis of organic phosphate forms by phosphatases and phytase producing fungi of arid and semi-arid soils of India. *Am Eurasian J Agric Environ Sci*, *5*(4), 564-70.
13. Shen, J., Yuan, L., Zhang, J., Li, H., Bai, Z., Chen, X., Zhang, W., & Zhang, F. (2011). Phosphorus dynamics: from soil to plant. *Plant physiology*, *156*(3), 997–1005.
14. Pikovskaya, R. I. (1948). Mobilization of phosphorous in soil connection with the vital activity of some microbial species". Microbiologiya 17: 362-370. *Plant Soil*, *287*, 77-84.
15. Afzal, A., & Bano, A. (2008). Rhizobium and phosphate solubilizing bacteria improve the yield and phosphorus uptake in wheat (Triticum aestivum). *Int J Agric Biol*, *10*(1), 85-88.
16. Kalayu, G. (2019). Phosphate solubilizing microorganisms: promising approach as biofertilizers. *International Journal of Agronomy*, *2019*, 1-7.
17. Gyaneshwar, P., Naresh Kumar, G., Parekh, L. J., & Poole, P. S. (2002). Role of soil microorganisms in improving P nutrition of plants. *Plant and soil*, *245*, 83-93.