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# PHOSPHATE SOLUBILIZING MICROORGANISMS: ITS MECHANISM AND ROLE IN SOLUBILIZING PHOSPHORUS IN SOIL

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Phosphorus in soil is present both in organic (phospholipids, nucleic acid, phytin) and inorganic forms; it is mostly taken up by plants in inorganic form as orthophosphate $H_2PO_4^-$ and $HPO_4^{2-}$. Phosphorous is the major nutrient, and required for plants in energy transfer and storage, root development, seed formation, nitrogen fixation in legumes, improvement of crop quality and in metabolic processes like photosynthesis. This phosphorus (P) content in soil is about 0.05% (w/w) but only 0.1% of the total phosphorus is available to plant because of poor solubility and gets fixed with $Al^{3+}$ and $Fe^{3+}$ in acidic soils and with $Ca^{2+}$ in alkaline soils, making them deficient and unavailable to plants. To correct this deficiency there has been wide used of phosphatic fertilizers throughout the world. However, there is a global concern about the ill effects of chemical fertilizers on the soil and its environment and also the huge cost involved, besides they are neither eco-friendly nor sustainable. In the recent years, progresses are made to deviate from use of chemical fertilizers to exploring the potential of beneficial soil microorganisms and use them as 'biofertilizers'. One such important biofertilizer is the phosphorus solubilizers.

Phosphorus solubilizers are those microorganisms (PSMs) which, through their various mechanisms of solubilization and mineralization are able to convert the unavailable form into bioavailable form facilitating increase uptake by plant roots. P solubilizing microorganisms excrete organic acids such as citric acid, lactic acid, gluconic acid, acetic acid, succinic acid, *etc*. which solubilized P into the soluble form. Soil bacteria belonging to genus *Pseudomonas, Bacillus*, *Agrobacterium*, *Azotobacter*, *Rhizobium*, *Enterobacter etc.* and fungi group including *Trichoderma*, *Penicillium*, *Aspergillus*, *Fusarium* and vesicular arbuscular mycorrhiza (VAM) *etc*. have been reported to function as P solubilizers.

Additionally, actinomycetes in the genera *Actinomyces*, *Streptomyces* and *Micromonospora* are also capable of solubilizing inorganic P.

## Importance of PSM to Plant Growth

Plants deficient in phosphorus are generally accompanied by symptoms of stunted growth, chlorosis, poor root elongation and development, abnormally dark green color owing to accumulation of carbohydrate. There is a direct form of interaction between plants and microbes as they live in close association. It has been reported that phosphate solubilizing microorganisms contribute to soil P pools, constituting about 0.4% to 2.4% of total P in arable soils. These microbes acting as P solubilizers have synergistic effect and contribute to the overall growth and development of crops. They promote plant growth through production of phytohormones such as auxin, zeatin, gibberellins and cytokinins. These growth promoting hormones helps in seed germination, root elongation, hasten maturity and improve quality of crops. Phosphate solubilizers not only solubilize phosphate but also other micronutrients and trace elements which increase their availability for plant uptake. They also produce siderophores as well as chelate elements and helps in mobilization of nutrients. Besides their role as P solubilizers they also inhibit the growth of phytopathogens by producing antibiotics and antifungal metabolites. PSM also support the growth of plants by improving the efficiency of biological nitrogen fixation besides synthesizing phytohormones. They stimulate the root and shoot growth, improve the root and shoot length, thereby enhance their biomass and also increases P uptake.

## Mechanisms of P Solubilization

High amount of phosphorus constituting 95-99% are present in insoluble form bound to other elements like iron, aluminium and calcium. These are unavailable to plants for uptake, and so soils are found to be deficient in available phosphorus. Fortunately, there exists a group of microorganism whose job is to solubilize the insoluble phosphorus and release them into the soil solution. These microorganisms called as ‘phosphorus solubilizing microorganism’ releases or solubilize phosphate through various mode of actions. Phosphorus solubilizing activity by microbes is determined by their mechanism in lowering pH through production of different organic acids, chelation and mineralization (Fig.1). Thus, microorganisms have key role in the soil P cycle i.e. precipitation, sorption–desorption, and mineralization.

*(i)* *Production of organic acids*

The principal mechanism involved in solubilization of phosphates is the production of various low molecular weight organic acids such as oxalic, citric, lactic, gluconic, acetic, malic, succinic, tartaric, fumaric acids. The secretion of organic acids results in lowering of the soil pH which acidify the microbial cells and the surrounding creating an environment favorable for release of P bounded by ions. Another mechanism to production of organic acid is achieved through the release of $H^+$ ions to the outer surface in exchange for cation uptake or with the help of $H^+$ translocation ATPase. Among all the organic acids produced, it is reported that gluconic acid accounts for the most frequent released acid facilitating the solubilization of phosphorus. They chelate or substitute those cations which are bound to phosphorus and release it, thereby making it available to plant. There are also certain inorganic acids such as nitric, sulphuric, and carbonic whose production helps in phosphate solubilization. Their contribution and effectiveness, though, is much lower as compared to organic acids.

*(ii)* *Liberation of enzymes*

The second mechanism of microbial phosphate solubilization is the release of enzymes by microbes or by enzymolysis. Phosphate is solubilized to the solution by three groups of enzymes- non-specific phosphatases, phytases, and phosphonatases and C-P lyases. These enzymes play a vital role in mineralization and dissolution of P in the rhizosphere. They hydrolyze a wide range of organic P compounds in soil and releases P in available form for plant uptake. Non-specific phosphatases dephosphorylate phospho-ester or phosphor-anhydride bonds of organic matter. Based on the soil reaction, they could be acid (predominant in acid soils) and alkaline (abundant in alkaline) phosphomonoesterases, both of which are produced by phosphate solubilizing microorganisms. However, the relationship between phosphate solubilizers introduced into soil, phosphatase activity and the subsequent mineralization of phosphorus remains not fully explored and understood. The other enzyme phytases helps in release of P through the process of phytate degradation. Phytate is the primary source of organic form of phosphorus ‘inositol’, constituting about 35% of P stored in plant seeds and pollen., *(iii) Chelation*

Phosphorus solubilization is also carried out by chelation mechanism. The process involves the release of hydroxyl and carboxyl group of acids where they chelate other cations such as Fe, Al and Ca bounded to phosphate and dissolve P into the solution. When PSM are present they interact with other cations which are bound to P as Fe-P, Al-P and Ca-P, bind them to their site through chelation mediated process and freed the P, making them available to plants for utilization. Another such mechanism is the production of hydrogen sulphide ($H_2S$) which react with ferric sulphate to yield ferrous sulphate with the release of phosphate.

*(iv) Mineralization*

PSM species possess the ability to mineralize and solubilize phosphorus and make them accessible to plants. Generally, phosphorus is bound to aluminium and iron as Al-P and Fe-P in acid soils, whereas, in alkaline soil it is present as Ca-P. While these forms are unavailable to plant efforts are made to solubilize phosphate through the role of PSM. Microorganisms belonging to *Bacillus* and *Streptomyces* species have the potential to mineralize those complex organic phosphates mostly through the release of enzymes such as phosphoesterases, phytases and phospholipases.

**Fig. 1** Different strains of PSM isolated from acid soils and their solubilizing capacity of phosphate with the clear halo form around the colonies in Pikovskaya's media

## Use of Phosphate Solubilizing Microorganisms as Biofertilizers

Over the years several species of bacteria and fungi have been subjected to mass production and used successfully as a biofertilizers. Subsequently their usage also helps in improving the phosphorus use efficiency. Bacteria, most commonly belonging to genus *Pseudomonas fluorescens*, *P. putida*, *Bacillus* species and fungi group *Trichoderma viride*, arbuscular mycorhizal fungi are used as PSM biofertilizers. They can be used for all crops and upon their application PSM enhanced the growth, quality and overall yield of many crops upto 40%. Table 1 shows the effect of application of PSM bioformulation on soil and change in soil properties before sowing and after harvest of crop.

**Table 1**. Effect of PSM strains bio-formulation in maize plant for seed treatment and soil application in pot experiment before sowing and after harvest of crop

| Sl. No. | Parameters | Time of analysis | pH | SOC (%) | Avail P (kg ha$^{-1}$) | Total P (%) |
|---|---|---|---|---|---|---|
| **1.** | Seed treatment | Initial | 4.95 | 0.42 | 7.02 | 0.38 |
| | | Final | 4.0- 5.2 | 0.26- 1.58 | 3.71 - 14.33 | 0.20-1.60 |
| **2.** | Soil application | Initial | 5.05 | 0.45 | 7.32 | 0.39 |
| | | Final | 4.1- 5.3 | 0.35-1.71 | 4.76-16.42 | 0.21-1.61 |

*SOC- soil organic carbon; Avail P- available phosphorus; Total P- total phosphorus

## Species of PSM in Acid Soil

Microorganisms have their own diversity and niche depending on the soil reaction and the surrounding environment. Potential phosphate solubilizing microorganisms found in acid soils are *Trichoderma viride*, *Aspergillus* sp., *Penicillium* sp., *Actinomyces*, *Mucor*, *Rhizobium*, *Klebsiella*, *Enterobacter aerogenes*, *Citrobacter freundi*, *Azospirillum* sp., *Azotobacter chroococcum* and *Pseudomonas* sp.

## Conclusion

There are considerable evidences pointing to the potential of PSM in enhancing the growth attributes and yield of many crops. Their efficiency, however, differs from strain to strain and from species to species depending upon the cultural and environmental conditions. The use of phosphate solubilizing microorganism as a microbial inoculants or biofertilizers serves a great purpose as alternative to chemical fertilizers besides acting as plant growth promoter and solubilising phosphate.

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