Also, it plays the vital role in root elongation, proliferation, and its deficiency affects root architecture [8, 9], seed development and photosynthesis, carbon metabolism, and membrane formation [7]. Phosphorus is important in several physiological processes of plants, especially in energy which is used for growth and reproduction. Phosphorus is a major growth limiting nutrient. As like nitrogen, phosphorus absorbed by the plant is accumulated grains as phytase, and is the major plant growth limiting nutrient despite its availability. Phosphorous (P) plays an important role in plant growth due to P-fixation, either it is adsorbed on the soil minerals or get precipitated by free Al3+ and Fe3+ in the soil solution [12, 13]. To increase the availability phosphorus to plants, a large amount of phosphorus is quickly applied to soil, a large portion of which is quickly transferred into insoluble form [14] and very little percentage of applied phosphorus is available to plants making continuous application fertilizer necessary [15]. Soil phosphorus dynamics is characterized by physicochemical and biological processes. A large amount of phosphorus applied as fertilizers enters into the immobile pools through precipitation reaction with highly reactive Al3+ and Fe3+ in acidic and Ca2+ in calcareous or normal soils [1, 16]. Organically bound phosphorus enters in the soil during the decay of natural vegetation, dead animals and from excretions. Although phosphorous it, present in the soil is insoluble and cannot be utilized by plants [11]. The changing scenario demands to adapt the strategies/approaches to convert an unavailable fraction of soil P into available form for plant uptake. Among the various strategies known for this purposes, use of specific microflora is considered as one of the most efficient means to solubilize insoluble soil P. Although microbial inoculants are in use for improving soil fertility during last century, however rarely sufficient work has been reported on Phosphate Solubilizing Microorganisms as compared to nitrogen fixation. Phosphate solubilizing microbes have the potential of making these phosphates available to the plants. Similarly, starch, as well as cellulose-degrading microbes, can degrade these complex carbohydrates and increase the soil fertility. Phosphate solubilizing bacteria (PSB) are being used as biofertilizer since the 1950s [17, 18]. There are also some evidence of naturally occurring rhizospheric phosphorus solubilizing microorganism (PSM) since 1903 [19]. Bacteria are more effective in phosphorus solubilization than fungi [20]. Among the whole microbial population in soil, Phosphate Solubilizing Bacteria (PSB) constitute 1 to 50 %, while phosphorus is solubilizing fungi (PSF) are only 0.1 to 0.5 % in P solubilization potential [21]. The bacterial strain isolated from alkaline soil can solubilize phosphates at high salt, high pH and high-temperature concentration [22, 23]. Many phosphate solubilizing bacteria are reported as plant growth promoter in many crops like tomato, rice etc [22, 24-27].

Diversity of PSM
There is a myriad of microorganisms, especially the Phosphate Solubilising Microorganisms (PSM) present in the soil. Some of the most common examples are the species of Pseudomonas, Bacillus, Micrococcus, Flavobacterium, Aspergillus, Penicillium, Fusarium, Sclerotium, etc. Strains from bacterial genera Pseudomonas, Bacillus, Rhizobium and Enterobacter along with Penicillium and Aspergillus fungi are the most powerful P solubilizers [28]. Bacillus megaterium, B. circulans, B. subtilis, B. polymyxa, B. sircalouis, Pseudomonas striata, and Enterobacter are referred as the most important strains.
Commonly there are more bacilli in soil whereas spirilli are very rare in natural environments [31]. The PSB are ubiquitous with variation in forms and population in different soils. The population of PSB depends on different soil properties (physical and chemical properties, organic matter, and P content) and cultural activities [32]. Larger populations of PSB are found in agricultural and rangeland soils [33].

**Isolation and identification of phosphate solubilizing microorganisms**

To isolate, the Phosphate Solubilizing Microorganisms, Pikovskaya’s medium is prepared. It is mixed with gum arabic and autoclaved and dispensed in Petri plates. Generally a small amount of soil, approximately 1 gm of soil is taken from the field and serially diluted in the known volume of water. Each plate is inoculated with 1 ml of sterile soil water suspension. Plates are incubated at 28°C for about 5 to 7 days. Only Phosphate Solubilizing Microorganisms grow and form the colony which can be identified due to the formation of a clear zone around each colony. It is only because the microorganisms grow and utilize calcium phosphate. Such colonies of a clear zone around each colony. It is only because the identification of PSM strains [34].

According to the literature, the Pikovskaya’s agar medium (PVK) was found to be as selective media for the isolation of PSM [35]. pH is maintained at 7.0. The composition of the medium was as given in the table mentioned above (Table 1).

**Table 1: Composition of pikovskaya’s agar medium (PVK)**

<table>
<thead>
<tr>
<th>Glucose</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yeast Extract</td>
<td>0.5</td>
</tr>
<tr>
<td>(NH₄)₂SO₄</td>
<td>0.5</td>
</tr>
<tr>
<td>MgSO₄.7H₂O</td>
<td>0.1</td>
</tr>
<tr>
<td>Ca₃(PO₄)₂</td>
<td>5</td>
</tr>
<tr>
<td>NaCl</td>
<td>0.2</td>
</tr>
<tr>
<td>KCl</td>
<td>0.2</td>
</tr>
<tr>
<td>MnSO₄.2H₂O</td>
<td>0.002</td>
</tr>
<tr>
<td>FeSO₄.7H₂O</td>
<td>0.002</td>
</tr>
<tr>
<td>Agar</td>
<td>15</td>
</tr>
</tbody>
</table>

The phosphate solubilizing microorganisms solubilize 20%-30% phosphate which is then absorbed by plants. The PSM can be used for all types of plants because they are heterotroph and show host specificity.

**Mechanism of action of PSM**

The efficiency of P fertilizer throughout the world is around 10-25% [36] and concentration of bioavailable P in soils is very low reaching the level of 1.0 mg kg⁻¹ soil [37] plants can absorb phosphate only in soluble form. The transformation of insoluble phosphate into soluble form is performed by a. Soil microorganisms play a key role in soil P dynamics and subsequent availability of phosphate to plants [38]. Phosphate Solubilizing Microorganisms (PSMs) especially Phosphate Solubilizing Bacteria (PSB) enhance the solubilization of insoluble phosphorous compounds through the release of organic acids and phosphatase and phytase enzymes[4] which is present in a wide variety of soil microorganisms. Species such as *Pseudomonas*, *Mycobacterium*, *Micrococcus* and *Flavobacterium* among bacteria and *Penicillium*, *Sclerotium*, *Aspergillus* and many other fungi are active in the conversion. During the conversion process, a part of phosphorous is assimilated by microorganisms, but the amount made soluble and released is in excess to the requirement of the microorganisms. The excess amount thus released is made available to plants. During this conversion process, organic acids play an important role. Equally important are nitric acid and sulphuric acid. As a result, these organic and inorganic acids convert calcium phosphate to di or monobasic phosphates and are then easily made available to plants phosphates [19, 39-41]. The amount of carbohydrates being oxidized by heterotrophs has a great impact upon the solubilization process. Nitric and sulphuric acid are produced by the oxidation of nitrogenous materials or inorganic compounds of sulfur, act upon rock phosphate [34]. During this process phosphate, solubilization is affected by nitrification of ammonium salts. Generally, the solubilization of phosphate is achieved by acid production [2, 3]. Mobilization of ferric phosphate requires certain bacteria which liberate hydrogen sulfide. A number of phosphate dissolving microorganisms are also known well in soil. It is also known that root region is abundantly rich in phosphate dissolving microorganisms. Due to this, the phosphate assimilation by higher plants is an increased. The mycorrhizal fungus also increases the fertility of soil up to a moderate extent [42]. Many bacteria, fungi, and actinomycetes also release bound phosphorus in crop residues and soil organic matter which is ultimately available to plants. Also, mesophilic and hemophilic bacteria’s actively participate in the mineralization of phosphorus [19] Warm temperature usually favors decomposition and due to this thermophilic species have an important role to play [26]. P² of soil is also important in the process [12]. As like nitrogen, phosphor is both mineralized and immobilized in soil. Both these process operate in soil and are governed by the amount of phosphorus in the plant residues undergoing decomposition and the nutrients required for the associated microbial population. Phosphate is formed when the ratio narrows with time due to CO₂ volatization (Table 2).

**Table 2: Some of the important PSM and their mode of action**

<table>
<thead>
<tr>
<th>PSM Type</th>
<th>Metabolite forms (acids)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSB</td>
<td>NOT Determined (ND)</td>
<td>[35]</td>
</tr>
<tr>
<td>E. freundii</td>
<td>Lactic acid</td>
<td>[7]</td>
</tr>
<tr>
<td>A. niger, Penicillium sps</td>
<td>Citric, gluconic</td>
<td>[43]</td>
</tr>
<tr>
<td>Penicillium rugulosum</td>
<td>2-Keto gluconic</td>
<td>[44]</td>
</tr>
<tr>
<td>Enterobacter intermedium</td>
<td>Oxalic, Citric, gluconic, succinic</td>
<td>[45]</td>
</tr>
<tr>
<td>Aspergillus flavus, A. niger, penicillium canescens</td>
<td>Oxalic, Gluconic</td>
<td>[46]</td>
</tr>
<tr>
<td>P. fluorescens</td>
<td>Citric, malic, tartaric, gluconic</td>
<td>[47]</td>
</tr>
<tr>
<td>Arthrobacter</td>
<td>Citric, malic, tartaric, gluconic</td>
<td>[48]</td>
</tr>
<tr>
<td>Enterobacter</td>
<td>Citric, alk,tartaric,gluconic, fumaric</td>
<td>[48]</td>
</tr>
<tr>
<td>P. trivalis</td>
<td>Lactic, formic</td>
<td>[49]</td>
</tr>
<tr>
<td>Pseudomonas putida MSTSA, Enterobacter sakazakii, M2PFe and bacillus megaterium M1PCa</td>
<td>Malic,gluconic</td>
<td>[50]</td>
</tr>
<tr>
<td>Enterobacter sps Fs 11</td>
<td>Citric,gluconic,oxalic</td>
<td>[51]</td>
</tr>
<tr>
<td>A. nigerFS 1, Penicillium canescens FS23, Eupenicillium ludwigii FS 27, Penicillium islandicum FS 30</td>
<td>Malic,gluconic,oxalic</td>
<td>[52]</td>
</tr>
<tr>
<td>Pseudomonas nitreducens</td>
<td>Indole acetic acid</td>
<td>[53]</td>
</tr>
</tbody>
</table>

Table modified from: [4, 12]
Biotechnology and PSMs

Nowadays research has been focused on isolating different PSM and using them as biofertilizers as well. The role of biotechnology has a great impact on modifying these PSM by the use of genetic engineering. Researchers are now trying to characterize those PSM which are efficient in the phosphorous intake and promoting plant’s growth as well [25] [12] concluded that PSM may be a sustainable approach for managing phosphorous deficiency in agricultural soils. Pannar et al, 2014 reported the use of PSSB to increase the fertility of sulfate soil which was later used for cultivating rice crop. Recently studies have demonstrated that 16 s rRNA gene sequencing can give the phyllogenetic relationship between PSB [54].

CONCLUSION

It is attractive to speculate that PSM through their mechanism of action can stimulate plant’s nutritional intake capacity and growth as well. Because of phosphate solubilization, auxin, and HCN production ability, it is very obvious that these microorganisms (PSM) should be exploited more and could be used as an efficient alternative to the chemical fertilizer in future. Extensive research work needed to be done to achieve methods how to commercialize these PSM as biofertilizers. Greater attention should be paid towards the improvement of PSM strains.

CONFLICT OF INTERESTS

Declared none

REFERENCES

38. Richardson AE. Soil microorganisms and phosphorus availability. In: Soil Biota, Management in sustainable farming


