



Phosphate Solubilizing Bacteria in Optimizing Phosphorous Acquisition and Crop Production

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Abstract: Phosphorous is a key essential element for overall plant life cycles and today its availability in the soil is a great challenge due to quick fixation in different soil types. Today the only solution on the hands of farmers is using chemical fertilizer. However, synthetic fertilizer have numerous negative impacts on environment, soil fertility depletion, human healthy and the microbial diversity and ecology. Using microorganisms as bio-fertilizers would be the viable complementary option for the livelihood of farmers and the environment. Those microbes speed up the microbial process immediately after directly added to soil or through seed treating as bio fertilizer and growing their population. This process facilitates the nutrient uptake of plant which is available for the targeted objectives. Groups of bacteria such as *Pseudomonas*, *Bacillus*, *Rhizobium* and *Enterobacter* etc. are the main phosphate solubilizing microbes through production of organic acid production and known as bio-fertilizer for cereal crops. However, still there are little awareness and huge knowledge gap on the importance of those microbes on their contribution for agricultural inputs. This review articles therefore summarizes the different mechanisms on how phosphate solubilizing bacteria make available inert phosphorous and information related with phosphate solubilizing bacteria.

Keywords: Bacteria, Biofertilizer, Microorganism, Phosphorous Fixation

1. Introduction

Phosphorous is an essential element which is irreversible and a building block of our life and have numerous function (energy metabolism, nucleic acid and protein synthesis, kinase regulation) [1]. It also involved in metabolic processes of plant, as photosynthesis, energy transfer, signal transduction, macromolecular biosynthesis and respiration [2]. Phosphorous deficiency affect i) decrease crop yield production in agriculture through different mechanisms, ii) affect genetic role of cell in DNA strand, and iii) cause disease to mankind due to phosphorous deficiency in the body. Soil is the primary source of phosphorous and taken up by plant. However, only 0.1% of phosphorous can be utilized by plants, rendering available phosphorous a restrictive factor for plant growth [3, 4]. From Phosphate fertilizer added to soil for crop production, (75-90%) precipitate by metallic

cation and are extremely reactive, become fixed through interactions with Ca^{2+} , Fe^{3+} , and Al^{3+} ions in the soil to form insoluble phosphate salt complexes [5, 6].

The realization of all these potential problems associated with chemical P fertilizers together with the enormous cost involved in their manufacture, has led to the search for environmental compatible and economically feasible alternative strategies for improving crop production in low or P-deficient soils [7]. The utilization of microorganism with the goal at enhancing nutrient availability for plants is a significant practice and is essential for agriculture [8]. Hence, Phosphate solubilizing microbes are an eco-friendly and a novel approach of keeping world food security [9].

This microorganism influence the plant growth in different mechanism directly through solubilizing unavailable phosphorous and indirectly through attacking pathogenic mechanism, initiating plant growth hormones and decaying organic matter and changing soil physicochemical properties

[10]. This all process boosts the agricultural yield product and keeps world food security and makes the environment safe. Today, the human interest is focused on yield through application of synthetic phosphate fertilizer and the knowhow for the contribution of microbes is at very limited stage. In case, atmospheric nitrogen fixing microbes especially rhizobia as a bio-fertilizer for leguminous crops currently are in good progress. Although microbial-based bio formulations that increase plant performance are greatly needed [11], bio-fertilizer for the case of cereal crops to minimize the application of synthetic phosphate fertilizer is the research gap in today's world. Therefore, the aim of this review articles was focused on the knowledge sharing about the contribution of phosphate solubilizing bacteria on the growth of plant and the impact on the grain yield production.

2. Phosphorous Fixation

The term phosphorous fixation is used to describe reactions that eliminate accessible phosphate from the soil solution into the soil solid phase [12] through phosphate sorption on the surface of soil minerals and precipitation of phosphate by free Al^{3+} and Fe^{3+} in the soil solution [13].

Therefore, soil phosphorous becomes fixed and available P levels have to be supplemented on most agricultural soils by adding synthetic P fertilizers, which not only represent a major cost of agricultural production but also inflict adverse environmental impacts on overall soil health and degradation of terrestrial, freshwater and marine resources [14].

3. Factors Affecting the Availability of Phosphorous in the Soil

Although there are abundant phosphorous in soils, in both organic and inorganic forms, its availability is restricted as it occurs mostly in insoluble forms. The phosphorous content in average soil is about 0.05% (w/w) but only 0.1% of the total P is available to plant because of poor solubility and its fixation in soil [15]. Availability of phosphorus to plants uptake is influenced by different factors i.e., soil pH, soil compaction, soil aeration, soil moisture, temperature, texture and organic matter of soils, crop residues, extent of plant root systems, minerals already present in the soil and root exudates secretions and available soil microbes [16]. In the case of acidic soils, phosphorous fixation is occurred by soluble form of Fe, Mn and free oxides and hydroxides of aluminum. But, in alkaline soils soluble phosphate ions quickly react with calcium to form a sequence of products of decreasing solubility [17]. The low availability of phosphorus in saline soil is attributed to its fixation with calcium, aluminum and iron that is then unavailable to plants [18].

Therefore, soil P dynamics is characterized by physicochemical (sorption-desorption) and biological (immobilization-mineralization) processes. Large amount of P applied as fertilizer enters in to the immobile pools through precipitation reaction with highly reactive Al^{3+} and Fe^{3+} in

acidic, and Ca^{2+} in calcareous or normal soils [19, 20]. Hence, phosphate solubilizing microbes are a critical solution where phosphorus nutrient are regarded as a limiting nutrient in agricultural soils.

4. Mechanism of Phosphate Solubilization

Phosphorus solubilizing is carried out by a large number of saprophytic bacteria and fungi through various mechanisms including acting on sparingly soluble soil phosphates, mainly by chelation-mediated mechanisms [21], organic acid production and proton extrusion [22]. Organic acid and mineral acids, alkaline phosphatases, phytohormones and H^+ protonation [23] anion exchange, chelation and production of siderophores are entirely promote phosphorous solubilization in soil [24]. Secretions of organic acids from phosphate solubilizing bacteria are potentially playing a crucial role for the mechanism of solubilization through dissolving insoluble soil phosphorous [25].

Inorganic Phosphorous is solubilizing by the action of organic and inorganic acids secreted by phosphate solubilizing bacteria in which hydroxyl and carboxyl groups of acids chelate cations (Al, Fe, and Ca). These acids acidify phosphate conjugate bases increasing their solubility as a result of the reduction of soil pH, while also chelating metals [26]. They also dissolve the soil phosphorous through production of low molecular weight organic acids mainly gluconic and keto gluconic acids [27, 28], in addition to lowering the pH of rhizosphere. The pH of rhizosphere is lowered through biotical production of proton / bicarbonate release (anion / cation balance) and gaseous (O_2/CO_2) exchanges. Peishi et al. [29] also suggested that production of key acids, such as propionic acid and oxalic acid, is especially important for the main mechanism used by PSM for dissolving phosphorus in saline environments.

Role of organic acids in mineral phosphate solubilizing is escorted through medium acidification [30]. Accordingly, the availability of the phosphorous to the plant is enhanced when the organic and inorganic acids convert tricalcium phosphate to di and mono basic phosphates. Based on their potential type and species, different phosphate solubilizing bacteria produce various potential. The type of organic acid produced and their amounts differ with different organisms.

Additionally, there are also numerous organic acids which were identified for the purpose of solubilizing phosphate such that oxalic acid, acetic acid, tartaric acid and etc. [31]. Among the organic acids secreted by those microbes, aliphatic acids have the potential to solubilize soil phosphorous [32]. Phosphate solubilizing microbes are also known to produce acidity by CO_2 evolution (carbonic acid); this kind of acidification was observed in solubilizing of calcium phosphates. Certain of phosphate solubilizing bacteria, under anaerobic conditions release H_2S which reacts with insoluble ferric phosphate to yield solubilized ferrous sulphate. Microbial biomass assimilates soluble P, and prevents it from adsorption or fixation [33]. Phosphate solubilizing bacteria are also solubilizing phosphorous through the production of

siderophores [34]. The secretion of phenolic compounds and humic substances is also reported [35].

5. Factors Affecting Phosphate Solubilizing Bacteria in the Soil

P-solubilizing is a complex phenomenon, which depends on many factors such as nutritional, physiological and growth conditions of the culture [36]. Larger populations of phosphate solubilizing bacteria are found in agricultural and range land soils [37].

Population of PSB also depends on different soil properties and affected by physical and chemical properties, organic matter, and P content and cultural activities. These physicochemical properties of soil inhibit the metabolic activities of organism. The concentration of iron ore, temperature, and C and N sources greatly influence the P solubilizing potentials of these microbes. Among the various nutrients used by these microorganisms, ammonium salts has been found to be the best N source followed by asparagine, sodium nitrate, potassium nitrate, urea and calcium nitrate [38].

Application of phosphate fertilizer also negatively affect the microbial activities in the soil includes inhibition of substrate-induced respiration by streptomycin sulphate (fungal activity) and actidione (bacterial activity) and microbial biomass carbon (C) [39]. Similarly, the application of triple superphosphate has shown a substantial reduction in microbial respiration and metabolic quotient (qCO_2) [40].

Pesticides may adversely affect the proliferation of beneficial soil microorganisms and their associated biotransformation in the soil through inactivation of nitrogen-fixing and phosphorus solubilizing microorganisms [41]. Microbial organic compound mineralization and associated biotransformation such as nutrient dynamics and their bioavailability are more or less adversely affected by pesticides [42]. Although the pesticides used in low concentration, they affect the growth of soil microorganisms, chemical and biological properties, biochemical activity [43]. However, the effect of pesticides on soil microorganisms and their activity depend upon the type of pesticides used, quantities and soil conditions [44].

6. Effects of Phosphate Solubilizing Bacteria on Growth and Yields of Different Crops

Phosphate solubilizing bacteria increase crop yield through modification of plant root properties [45]. Improving biological nitrogen fixation is an additional importance of phosphate solubilizing bacteria in encouragements of plant growth [46]. According to the research findings [47], pseudomonas species are the principal phosphate solubilizing bacteria and also enhance nutrient availability, increase nodule number, dry weight, and improve yield and yield

components of soybean. They also improved the seedling length of *Cicer arietinum* [48] and increased sugarcane yield by 12.6% [49], could also boost yields of many crops apple, maize, soybean, sugar beet, chickpea and peanut [50-55].

Phosphate solubilizing bacteria have a multifunctional goal in plant growth and biosynthesis in addition to availing phosphorus to plant. They also have value in making essential growth promoting hormone substance, initiate the availability of atmospheric nitrogen, make available trace essential elements and generally facilitate plant growth [56]. Additionally, they have also important as biocontrol through facilitating iron (siderophores), antibiotics and providing protection to plants against soil borne pathogens [57-59]. Accordingly, these microbial communities when used singly [60] or in combination with other rhizosphere microbes have shown substantial measurable effects on plants in conventional agronomic soils [61]. PSM isolated from soils can produce IAA and can increase the extension of roots in the soil, thus causing phosphorus to become more available to the roots and therefore, phosphate solubilizing bacteria, promoting plant growth under saline conditions [62, 29]. Phosphate solubilizing bacteria has important role in the secretion of extra polysaccharides and these extra polysaccharides important in improving salt stress through binding to Na^+ and decrease sodium ion uptake by plants [63].

Phosphate solubilizing bacteria specially *Pseudomonas* genus can produce siderophore and used to improve uptake of iron ion by plant under saline stress [64, 29]. Root associated microbes, including endophytes, closely cooperate with each other and can mediate important physiological processes, especially nutrient acquisition and plant fitness to abiotic stresses [65, 66].

The beneficial effects of PSB involve boosting key physiological processes, including water and nutrient uptake, photosynthesis, and source-sink relationships that promote growth and development [67]. The distinctive characteristics of PSB are they must be able to colonize the root, they must survive and multiply in microhabitats associated with the root surface, in competition with other microbiota, at least for the time needed to express their plant promotion/ protection activities and they must promote plant growth [68, 69].

Use of PSMs can increase crop yields up to 70 percent [70]. Combined inoculation of arbuscular mycorrhiza and PSB give better uptake of both native P from the soil and P coming from the phosphatic rock [71, 72]. Phosphate solubilizing bacteria enhanced the seedling length of *Cicer arietinum* [48], while co-inoculation of PSB and PGPR reduced P application by 50% without affecting corn yield. Sole application of bacteria increased the biological yield, while the application of the same bacteria along with mycorrhizae achieved the maximum grain weight.

Phosphate solubilizing bacteria also improve the uptake of other essential elements such as nitrogen, and potassium and also used as biocontrol agents of phytopathogenic fungi, synthesizing phytohormones in the root zone and rhizosphere, resulted in promote plant growth and development [73].

7. Synergy of PSB with Other Microbes in the Soil

Some phosphate-solubilizing bacteria behave as mycorrhizal helper bacteria and interact with arbuscular mycorrhizae (AM) by releasing phosphate ions in the soil, which causes a synergistic interaction that allows for better exploitation of poorly soluble P sources [74]. Therefore, the phosphorous solubilizing by this system can easily uptake through mycorrhizae-mediated bridge between roots and surrounding soil that allows nutrient translocation from soil to plants [75]. Toro et al. [76] also demonstrated that phosphate solubilizing bacteria associated with AM improved mineral nitrogen and phosphorous accumulation in plant tissues. Other research findings also suggested that Arbuscular mycorrhizal fungi (AMF) and phosphate solubilizing *Pseudomonas* bacteria (PSB) could potentially interact synergistically because PSB solubilizing phosphate into a form that AMF can absorb and transport to the plant [77]. Although AMF can only exploit soluble P sources and much P in the soil is in an insoluble form, the capacity of AMF to transport P to the plant, can add up to 70% of total P plant uptake, is well known [78]. Synergistic effects between nitrogen fixing bacteria and phosphate solubilizing bacteria were obvious; co-inoculations with nitrogen fixing bacteria enhanced the accumulation of available P and greater performance in plant growth promotion [79].

Grain yield of wheat (*Triticum aestivum* L. is increased due to application of phosphate solubilizing bacteria biofertilizer *Pseudomonas* and *Bacillus* species through improving availability of phosphorous nutrient in the soil, the plant easily access it [80]. Integrated application of phosphorous solubilizing bacteria and inorganic phosphate fertilizer improve grain yield of wheat up to 30-40% times when compared to phosphorous fertilizer alone [81].

8. Types of Phosphate Solubilizing Bacteria

In agricultural soil, the populations of phosphate solubilizing bacteria are the dominant which account for 1 to 50% whereas the fungi populations constitute small amount only 0.1 to 0.5% [82]. Among the soil bacterial communities ectorrhizospheric strains from *Bacillus* and *Pseudomonas* [61] and endosymbiotic rhizobia have been described as effective phosphate solubilizers [83]. Strains from bacterial genera *Pseudomonas*, *Bacillus*, *Rhizobium* and *Enterobacter* and *Aspergillus* and *Penicillium* from fungal genera [84] are the most powerful phosphate solubilizers [21]. In the same manner, Sharma et al. [4] also reported that *Pseudomonas*, *Mycobacterium*, *Micrococcus*, *Bacillus*, *Flavobacterium*, *Rhizobium*, *Mesorhizobium* and *Sinorhizobium* are best phosphate solubilizing strains involved in phosphate solubilizing bacteria.

The bacteria species used for phosphate solubilizer in the agricultural activity are listed that *Phyllobacterium*,

Chryseobacterium, *Gordonia*, *Rhodococcus*, *Arthrobacter* [82]. There were bacteria species which have dual purpose i.e., initiating phosphorous availability to plant through dissolving unavailable phosphorous and fixing atmospheric inert nitrogen into ammonia and used up by host plant. These type of activity is carried out by *Rhizobium leguminosarum*, *R. leguminosarum* bv. *Viciae* and *Rhizobium* species nodulating *Crotalaria* species [85-87] improved solubilizing phosphates by mobilizing inorganic and organic phosphorus.

Microorganisms have been isolated using cultural procedures with species of *Pseudomonas* and *Bacillus* bacteria [15] and *Aspergillus* and *Penicillium* fungi being predominant [88]. These organisms are ubiquitous but vary in density and mineral phosphate solubilizing ability from soil to soil or from one production system to another. In soil phosphorous solubilizing bacteria constitute 150% and fungi 0.1 to 0.5% of the total respective population. They are generally isolated from rhizosphere and nonrhizosphere soils, rhizoplane, phyllosphere, and rock P deposit area soil and even from stressed soils [7].

Bacillus and *Pseudomonas* spp. are the most frequent genus of phosphate solubilizing and were able to dissolve insoluble phosphorus, thereby increasing the available phosphorus content in soil [89]. Moreover, *Enterobacter*, *Streptomyces* and *Providencia rettgeri* spp. were phosphates solubilizer in saline soil and the latter genus was reported for the first time as a phosphate solubilizer [29]. However, the phosphorus-solubilizing ability of *Streptomyces* is low and indicates that bacterial agents are more suitable for use as PSMs.

Bacteria from genera such as *Achromobacter*, *Agrobacterium*, *Bacillus*, *Enterobacter*, *Erwinia*, *Escherichia*, *Flavobacterium*, *Mycobacterium*, *Pseudomonas* and *Serratia* are highly efficient in solubilising unavailable complexed phosphate into available inorganic phosphate ion [90]. *Rhizobia*, including *R. leguminosarum*, *R. meliloti*, *Mesorhizobium mediterraneum*, *Bradyrhizobium* sp. and *B. japonicum* are the potential phosphate solubilizers [91-93]. Through nitrifying bacteria and *Thiobacillus*, nitric acid and sulphuric acids (organic acids and inorganic acids respectively) produced during the oxidation of nitrogenous or inorganic compounds of sulfur which react with calcium phosphate and convert them into soluble forms [6].

9. Current Trends and Future Prospects of Phosphate Solubilizing Bacteria in Ethiopia

The successful implementation of phosphate solubilizing bacteria as bio-fertilizer has already been demonstrated in the fields by various workers, to a limited extent in different world countries. In Ethiopia, the application of phosphorous nutrient for crop production is still focused on chemical fertilizer. Moreover, the different agricultural experts in the country only limited to boosting the country production and productivity in any direction for cereal crops, vegetable crops,

industrial crops and etc. As an indicator, bacteria strain as inoculants for different crop production is an appreciating starting research done by Ethiopian researcher. Hence, Gizaw B, et al. [94] reported that *Phichia norvegensis* and *Cryptococcus albidus* var *aerius* were superior in phosphate solubilization and recommended as bio fertilizers for teff productivity. Additionally, Muleta D et al. [95] also suggested that *Pseudomonas* spp. and two *Erwinia* species and a *P. chlororaphis* strain isolated from coffee Arabica in southwestern Ethiopia and recommended as higher organic acid producer which capable of solublize fixed phosphorous in the soil and have traits for extending the use of indigenous microbes as microbial biofertilisers. Similarly phosphate solubilizing microbes from rhizosphere of fababean, teff at flowering stage, coffee Arabica, tef at seedling stage, white lupin were also recommended [96-100].

Although significant studies related to PSM and their roles in sustainable agriculture have been done across the globe as well as in Ethiopia, field evaluation, biofertilizer based large scale crop yield production technique remains in its infancy stage and the research result still not feasible at field condition.

Future research should focus on isolation of PSB, characterization, authentication, large scale demonstration, managing plant-microbe interactions, particularly with respect to their mode of actions and adaptability to conditions under extreme environments for the benefit of plants and finally ways and means for their better utilization in the farmers' fields to ensure conservation of our environments. Furthermore, scientists need to address certain issues, like how to improve the efficacy of bio-fertilizers, what should be an ideal and universal delivery system, how to stabilize these microbes in soil systems, and how nutritional and root exudation aspects could be controlled in order to get maximum benefits from PSM application.

10. Conclusion

Phosphorous is an essential macronutrient with huge challenge in the soil by its active fixation. This leads the minutes uptake of by plants in available forms and disturb overall metabolic activity of crops finally low grain yield in terms of quality and quantity. However, world population is increasing from time to time and needs concrete attention on how to keep the world food security. Therefore, to increase human demand considerable production of grain yield is imperative and the final decision we have is still using inorganic phosphate fertilizer. Though these options have beneficial effects, immediate phosphorous fixation during application, cost of production, transportation and availability to resource poor farmers, and finally hazardous to the environment and nutrient depletion is the other majestic problem. Furthermore, several times, these inorganic fertilizers are not accessible or too expensive for resource-poor famers. Hence, there is a strong need for novel, effective, affordable, integrated and durable strategies for crop yield improvement. To meet these challenges researcher have

better give attention towards PSB from all location and soil types to solve farmers problems for accessing bio-fertilizer which is cost effective, environmentally friend approach even maintaining the soil fertility for the coming generation and human health as well instead of chemical fertilizer. Hence, researchers will have explore the potential rhizospheric microbes (soil and plant micro biomes) as an effective, generic and environmentally-sound approach to improve crop productivity in the country and even better to avail the isolated phosphate solubilizing bacteria using the previous result for resource poor farmers.

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