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Review

Diversity, mechanism and biotechnology of phosphate solubilising microorganism in mangrove—A review

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ABSTRACT

Phosphorus (P) is one of the major essential macronutrients for biological growth and development of plants. Phosphorous in soil is mainly found as mineral phosphorous or organic phosphorous which is however insoluble and unavailable to the plants. Microorganisms, both bacteria and fungi play a central role in the natural phosphorus cycle and convert insoluble forms of phosphorus to an accessible form which is an important trait for the growth and survival of plants. Among the phosphate solubilizing microbes, strains from the bacterial genera *Pseudomonas*, *Bacillus* and *Rhizobium* and fungi such as *Pencillium*, *Aspergillus*, *Fusarium*, *Helminthosparium*, *Alternaria*, etc. are the most powerful phosphate solubilizers. Phosphorous solubilization by microorganisms is a complex phenomenon, which depends on many factors such as nutritional, physiological and growth condition of the culture. The principal mechanism for mineral phosphate solubilization is the production of organic acids where the enzyme phosphatases play a major role in the mineralization of organic phosphorous in soil. In recent years several phosphatases encoding genes have been cloned and characterized and a few genes involved in mineral phosphate solubilization have been isolated. Therefore, genetic manipulation for improvement of phosphate-solubilizing bacteria to improve plant growth may include cloning genes involved in both mineral and organic phosphate solubilization, followed by their expression in selected rhizobacterial strains is an interesting approach. Besides phosphate solubilizing activity of microorganisms, the present paper also reports biotechnological potentials of phosphate solubilizing microorganisms from mangrove environment which is a unique saline costal ecosystem of tropical and subtropical regions of the world.

Contents

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1. Introduction

Phosphorus (P) is one of the major essential macronutrients for biological growth and development (Ehrlich, 1990). It is the most limiting macronutrient after nitrogen for plant growth and is normally present at levels of 400–1200 mg kg^{-1} of soil (Fernández and Novo, 1988). Phosphorus is a frequently limiting macronutrient next only to nitrogen for plant growth and makes up about 0.2% of plant dry weight (Schachtmam et al., 1998). The plants obtain their P requirements from the soil pool. It occurs in soil as inorganic phosphate, produced by weathering of parent rock or as organic phosphate derived from decayed plant, animal or microorganisms. Mineral forms of phosphorus are represented in soil by primary minerals, such as apatite, hydroxyapatite and oxyapatite. The principal characteristic of these mineral forms is their insolubility. However, under appropriate conditions, they can be solubilised and become available for plants and microorganisms. Phosphorus is an integral part of the cellular activities of living organism. It has a defined role in plant metabolisms such as cell division, development, photosynthesis, breakdown of sugar, nutrient transport within the plant, transfer of genetic characteristics from one generation to another and regulation of metabolic pathways (Armstrong, 1988; Theodorou and Panxton, 1993). The cell might take up several P forms but the greatest part is absorbed in the forms of HPO_4^{2-} or $H_2PO_4^-$ (Beever and Burns, 1980). Mineral phosphate can also be found associated with the surface of hydrated oxides of Fe, Al and Mn, which are poorly soluble and assimilable. A second major component of soil P is organic matter. Organic forms of P may constitute 30–50% of the total phosphorus in most soils, although it may range from as low as 5% to as high as 95% (Paul and Clark, 1988). Organic P in soil is largely in the form of inositol phosphate (soil phytate). It is synthesized by microorganisms and plants and is the most stable of the organic forms of phosphorus in soil, accounting for up to 50% of the total organic P (Dalal, 1977; Anderson, 1980; Harley and Smith, 1983). Other organic P compounds in soil are in the form of phosphomonoesters, phosphodiesters including phospholipids, nucleic acids, and phosphotriesters. Of the total organic phosphorus in soil, only approximately 1% can be identified as nucleic acids or their derivatives (Paul and Clark, 1988). Many of these P compounds are high molecular-weight material which must first be bioconverted to either soluble ionic phosphate (Pi, HPO_4^{2-}, H_2PO^{4-}), or low molecular-weight organic phosphate, to be assimilated by the cell (Goldstein, 1994). Besides this, large quantities of xenobiotic phosphonates, which are used as pesticides, detergent additives, antibiotics, and flame retardants, are released into the environment. These C–P compounds are generally resistant to chemical hydrolysis and biodegradation, but recently several reports have documented microbial P release from these sources (McGrath et al., 1995, 1998).

Phosphorus cycle in the biosphere can be described as 'open' or 'sedimentary', because there is no interchange with the atmosphere. Microorganisms play a central role in the natural phosphorus cycle. This cycle occurs by means of the cyclic oxidation and reduction of phosphorus compounds, where electron transfer reactions between oxidation stages range from phosphine (-3) to phosphate ($+5$). The genetic and biochemical mechanisms of these transformations are not yet completely understood (Ohtake et al., 1996). The concentration of soluble P in soil is usually very low, normally at levels of 1 ppm or less (10 M $H_2PO_4^-$) (Goldsteinn, 1994).

2. Phosphorous in soil

Soil is a dynamic system and is an ecological niche of constant biological activity, influenced to a great extent by the chemical nature of its parent material and the plant growth it supports. The Pi available for biosynthetic purposes will depend not only on the total amount of phosphorus in the environment but also its solubility, which in turn is dictated by several chemical reactions and biological interactions in the soil. The diverse soil P forms can be generally categorized as soil solution P, insoluble organic and insoluble inorganic P. In soil, the two reactions, fixation and immobilization convert applied phosphorus into forms unavailable for the plant. More than 70–90% of the applied phosphatic fertilizers get fixed in the soil rendering them unavailable for plant uptake (Stevenson, 1986; Bhagyaraj and Verma, 1995; Holford, 1997). The decomposing roots also release phosphorus as a result of autolysis, directly into the soil solution mainly as inorganic orthophosphates. The ultimate result of this also is fixation (Martin and Cunninghum, 1973).

Great percentages of soil P is also converted to organic forms of which inositol hexaphosphate is usually a major component, and thus get immobilized and not available for plant growth (Richardson, 1994). The concept of conversion of inorganic unavailable phosphate into available forms viz., $H_2PO_4^-$ and HPO_4^{-2} for plant uptake is a phenomenon referred to as mineral phosphate solubilization (MPS). The form in which Pi exists also changes according to the soil pH. Below pH 6.0, most Pi will be present as monovalent H_2PO_4 species. The plant uptake is also high at the pH range of 5.0–6.0, which indicates that P is primarily taken up as monovalent form (Furihata et al., 1992). The average orthophosphate concentration in the soil solution of around 10^{-6} M is near the limit at which plants can absorb adequate phosphate.

3. Phosphorus in mangroves

Mangroves are very efficient mud traps, essential as physical substrate and nutrient source for forest development. Biogeochemical processes within the mangrove forest, mainly within