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Some possibilities for promoting Phosphorus solubilizing into the soil profile through microorganisms.

Potential PSMES (Phosphate Solubilizing Microorganisms)

	PSMs	Sources
Bacteria	*Bacillus circulans*	[2–5]
	Bacillus megaterium	[2–5, 12, 13]
	Bacillus polymyxa; B. subtilis	[2–4, 13, 14]
	Bacillus pulvifaciens	[15]
	Bacillus coagulans; B. fusiformis; B. pumilus; B. chitinolyticus	[2]
	Bacillus sircalmous	[3, 4]
	Thiobacillus ferrooxidans	[2]
	Pseudomonas canescens	[8]
	Pseudomonas putida	[2, 4, 14–17]
	Pseudomonas calcis	[2]
	Pseudomonas fluorescens	[2, 4, 13, 14, 17]
	Pseudomonas striata	[2–4, 13, 14]
	Pantoea agglomerans	[18]
	Rhizobium meliloti	[2]
	Rhizobium leguminosarum	[6, 13, 19]
	Mesorhizobium mediterraneum	[20]
Fungi	*Aspergillus nNiger*	[2, 8, 14, 21–24]
	Aspergillus clavatus	[8]
	Aspergillus awamori	[2, 3, 13, 14, 23, 25]

	Aspergillus candidus; A. parasiticus; Aspergillus fumigatues; A. rugulosus	[21, 24]
	Aspergillus flavus	[2, 14, 23]
	Aspergillus foetidus; A. nidulans; A. wentii	[2]
	Aspergillus terreus	[2, 21, 23, 24]
	Aspergillus tubingensis	[22]
	Aspergillus sydawi; A. ochraceus; A. versicolor	[23]
	Penicillium bilaii	[5, 13]
	Penicillium citrinum	[25]
	Penicillium digitatum; P. lilacinium; P. balaji; P. funicolosum	[2]
	Penicillium oxalicum	[14]
	Penicillium simplicissimum; P. rubrum	[21, 24]
	Arthrobotrys oligospora	[13, 14, 26]
	Trichoderma viride	[2, 14, 23]
	Acinetobacter rhizosphaerae	[27]
Actinomycetes	*Streptomyces albus; S. cyaneus; Streptoverticillium album*	[3]
Cyanobacteria	*Calothrix braunii*	[2]

Diversity of organic acid produced by PSMES.

PSM isolates	Organic acids	References
Bacillus sp.	Citric acid, malic acid, succinic acid, fumaric acid, tartaric acid, gluconic acid	[23]
Pseudomonas	Citric acid, succinic acid, fumaric acid, gluconic acid, 2-ketogluconic acids	[3, 23]
Proteus sp.	Citric acid, succinic acid, fumaric acid, gluconic acid	[23]
Aspergillus	Citric acid, gluconic acid, oxalic acid, succinic acid, malic acid, glycolic acid	[29]
Azospirillum sp.	Citric acid, succinic acid, fumaric acid, gluconic acid	[23]
Penicillium sp.	Gluconic acid, glycolic acid, succinic acid, malic acid, oxalic acid, citric acid	[29]
Erwinia herbicola	Gluconic acid, 2-ketogluconic acids	[3]
Thermotolerant acetic acid	Acetobacter, Gluconobacter	[3]

Effect of PSMES on growth and yield performance of different crops.

PSMs	Host plant	Reference
Azotobacter	Wheat	[9]
Azotobacter chroococcum	Wheat	[36]
Azospirillum spp.	Maize, sorghum, and wheat	[9]
Bacillus	Wheat 33 (*Triticum aestivum* L.)	[6, 9]
Bacillus	Peanut, potato, sorghum, and wheat	[9]
Bacillus circulans and Cladosporium herbarum	Wheat	[36, 37]
Bacillus megaterium and Azotobacter chroococcum	Wheat	[9]
Pseudomonas	*Zea mays* L.	[6, 38]
Pseudomonas	Soybean	[6, 18]
Pseudomonas chlororaphis and P. putida	Soybean	[36]
Pseudomonas fluorescent	Peanut	[39]
Pseudomonas putida and Pseudomonas fluorescens	Canola, lettuce, and tomato	[9]
Pseudomonas putida and Pseudomonas fluorescens	Potato, radishes, rice, sugar beet, tomato, lettuce, apple, citrus, beans, ornamental plants, and wheat	[9]
Mesorhizobium mediterraneum	Chickpea and barley	[20]

Conclusion

Application of PSM by inoculating in soil appears to be an efficient way to convert the insoluble P compounds to plant-available P form, resulting in better plant growth, crop yield, and quality. *Bacillus, Pseudomonas, Rhizobium, Aspergillus, Penicillium*, and AMR are the most efficient P solubilizers for increasing bioavailability of P in soil. PSM provokes immediate plant growth by providing easily absorbable P form and production of plant growth hormones such as IAA and GA. Furthermore, PSM supports plant growth through production of siderophore and increases efficiency of nitrogen fixation. Besides, PSM acts as a biocontrol against plant pathogens via production of antibiotics, hydrogen cyanate (HCN), and antifungal metabolites. Thus, PSMs represent potential substitutes for inorganic phosphate fertilizers to meet the P demands of plants, improving yield in sustainable agriculture. Their application is an ecologically and economically sound approach. Further investigation, therefore, is crucial to explore effective biofertilizers—PSM with multiple growth-stimulating attributes at the field trial. Yet a combination of rock phosphate with PSM inoculum sounds preferable in terms of minimizing the risk of long-term total P soil deficit.

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