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Microorganisms in the Rhizosphere and their Utilization in Agriculture: A Mini-Review

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Abstract
The soil microbial communities possess a complex and diverse structure. From an ecological point of view, the soil-inhabiting microbes owe a very important position because they are the leading drivers in regulating the composition of soil and distribution of other organisms. The microbes are pathogenic as well as non-pathogenic. The latter category, are generally known for their beneficial roles they offer to plants and other organisms. The beneficial flora of the microorganism comprises various fungi (arbuscular mycorrhiza fungi–AMF) and bacteria, generally referred to as plant growth promoting bacteria (PGPB). Both AMF and PGPB are regarded as the wealth of soil because they have potential abilities to improve the soil health and plant growth. These microbes provide nutrients and organic substances to plants, remove soil pollutants, and eliminate the pathogenic organisms found in soil. On the basis of plant growth improvement abilities, AMF and PGPB can be used in agriculture as biofertilizers. This review is an attempt to explore the beneficial attributes of soil microorganisms.
Keywords: Arbuscular mycorrhiza fungi, PGPB, growth regulation, biofertilizers, rhizosphere.

INTRODUCTION

The soil is an important ecological sphere which provides habitat to various organisms, both at micro as well as macro level. Nematodes, rodents, ants, termites, insects, and earthworms are macro-organisms which inhabit the soil. Plants are the main producers which grow on soils. Several fungi, algae, and bacteria are microorganisms found in the sphere. The compendium of these organisms is a necessary ecological factor which regulates the ecosystem functioning. Each category of organisms has a specific role in the stability of the ecosystem. Considering plants as a major group of interest for human beings, microorganisms found in the soil can be classified as beneficial or harmful (Lugtenberg and Kamilova, 2009). Harmful microbes cause severe diseases in plants and results in lower growth and yields. *Streptomyces* sp., *Pectobacterium* sp., and *Ralstonia* sp., are serious pathogens of potato, root-rot nematodes (*Meloidogyne* sp.) adversely affects potato and other tuberous crops (Saucet *et al.,* 2016; Smant *et al*., 2018), late blight caused by Phytophthora infestans, early blight, damping-off, and vascular wilt of different crops have a negative impact on the growth and yield of plants (Majeed and Muhammad, 2018; Majeed *et al*., 2018a). The negative consequences of the phytopathogens are generally managed with the use of broad-spectrum pesticides. The pesticide use is effective in minimizing losses posed by the pathogens; they are also major drivers in causing environmental pollution. Thus to handle the pathogens and reduce the use of pesticides, practicing some natural enemies for controlling the pathogens is an alternative solution (Iqbal and Ashraf, 2017).

Soil microbes which possess beneficial traits to improve the growth of plants are ideally best candidates for utilization. AMF and PGPR are diverse groups of microbes which possess several potentials of growth stimulation and biological control. These organisms have evolved complex mechanisms to confer benefits to host plants. Nadeem *et al*. (2014) have comprehensively provided evidence about the growth promotion and biocontrol potentials of AMF and PGPR in agriculture. Pérez-de-Luque *et al*. (2017) argued that AMF and PG bacteria are essential for the biological control of different plant diseases. Manila and Nelson (2017) outlined that AMF significantly improve the growth, nutrient uptake and suppresses diseases associated with maize crop. Xun *et al*. (2015) have revealed the importance of AMF and certain strains of PGPR in growth enhancement and biocontrol activity in oat. The aim of this review is to discuss AMF and PGPR and to propose their potential utilization in managed agriculture.

ARBUSCULAR MYCORRHIZA FUNGI (AMF)

AMF is a prominent group of fungi which are found in soil and make symbiotic association with different plants for mutual benefits (Yang *et al*., 2015). More than 80% of plants have been reported to form an association with AMF which helps plants to draw maximum water, nutrient and protection against pathogenic bacteria and fungi (Berruti *et al*., 2016). Some AMF species have reported to overcome drought stress in plants to a significant extent with improved nutrient uptake and growth performance (Saharan *et al*., 2018). AMF fungi are named as 'arbuscular fungi' due to their formation of branched structures 'arbuscules' (Bever *et al*., 2001). Their distribution is worldwide and prevalent in below ground where they form a mutualistic association with thousands of plants (Munkvold *et al*., 2004). Nearly all the AMF fungi generally belong to phylum Glomeromycota (Schüßler *et al*., 2001). The beneficial aspects of AMF have been well studied in empirical and theoretical works. Rillig *et al*. (2002) outlined that AMF contributes to the improvement of soil aggregation and its structure in a number of ways. Gonzalez-Chavez *et al*. (2004) revealed that AMF produces glomalin which is concerned with eliminating toxic substances from the soil. Harrier *et al*. (2004) proved documentary evidence about the biological activities of some AM fungi against soil-borne pathogens. Berruti *et al*. (2016) proposed the role of AMF as biofertilizers in agriculture because of their facilitating roles in soil nutrition, water absorption, and biocontrol activities. Ruscitti *et al*. (2017) described that AMF could potentially reduce the heavy metal stress (Cu) imposed on the pepper. Ruiz-Lozano *et al*. (2018) reported that a symbiotic association with AM fungi resulted in salinity tolerance, CO2 utilization and enhanced growth in rice. Elhindi *et al*. (2017) have also documented the role of AMF in reducing salt stress in sweet basil.

PLANT GROWTH PROMOTING BACTERIA

Bacterial species which have healthy effects on plants are termed as plant growth promoting bacteria (Glick, 2012). There are dozens of bacterial species which can enhance plant growth and metabolic functions by producing hormones, growth-stimulating substances, and facilitating the availability of nutrition in the soil for plants (Majeed *et al*., 2018b). The PGPB belong to diverse genera of bacteria. *Azotobacter, Acinetobacter, Enterobacter, Bacillus, Bradyrhizobium, Mesorhizobium, Pseudomonas*, and *Rhizobia* are among the most widely studied bacterial genera which possess plant growth promoting species (Shameer and Prasad, 2018). Majeed *et al*. (2017) presented a list of bacterial cyanophytes in improving the growth potential of the rice crop and fulfilling deficit nitrogen in fields. The PGPB can be free-living or they may be found in association with plants. Some examples of free-living PGPB are *Azotobacter sp., Pseudomonas* sp., *Mesorhizobium* sp., *Bacillus* sp. etc. (Ahmad *et al*., 2008) while species of *Burkholderia, Stenotrophomonas, Micrococcus, Pantoea, and*

Microbacterium are among the most commonly occurring endophytes in the rhizosphere (Santoyo *et al*., 2016).

Table 1. AMF and PGPB and their role in plants' growth in different conditions.

PGPB strains	AMF	Effects on plants	References
Azospirillum brasilense	*Laccaria tortilis*, *Cadophora* sp.	Improvement in root colonization, development, increase in root dry weight in common bean and *Salix* sp.	Remans et al. (2008); Baum et al. (2018)
Bacillus sp.	*Funneliformis mosseae*	Enhanced nutrient uptake, Stimulation of plant growth and grain yield in maize; root colonization and drought resistance in strawberry	Adesemoye et al. (2008); Boyer et al. (2015)
Pseudomonas aureantiaca, *P. extremorientalis*	*Rhizophagus irregularis*	Better germination, seedling growth, and root elongation, salinity tolerance in wheat; improved yield and biomass and acidity stress tolerance in chini squash	Egamberdieva (2009); Rouphael et al. (2015)
Pseudomonas sp.	*Glomus intraradices*	Drought tolerance, improved water potential, plant growth and biomass; increased biomass in onion	Deressa and Schenk (2008); Sandhya et al. (2010)
Mesorhizobium sp., *Variovorax paradoxus*	*Glomus fascicualtum*	Stress tolerance to Cd, Pb and Zn/ improved nutrient uptake, enhanced plant growth and biomass; shoot biomass improved in chili	Bagyaraj and Sreeramulu (1982); Safronova et al. (2012)
Bacillus pumilus	*Glomus mosseae*	Induced tolerance to drought, salinity and heavy metal stress, Better growth response in potato; shoot biomass enhanced and drought tolerance in Lactuca	Tobar et al. (1994); Gururani et al. (2013)
B. amyloliquefaciens, *A. brasilense*	*Glomus mosseae*, *G. clarum*, *G. etunicatum*, *G. intraradies*,*G. caledonium*	Induction of drought tolerance and improved seedling growth in wheat; root shoot improvement in tomato	Kasim et al. (2013); Ortas et al. (2013)
B. amyloliquefaciens	---------	Stimulated growth and better response to salinity stress in rice	Nautiyal et al. (2013)
Acinetobacter sp.	---------	Improvement of soil, increase in growth and shoot length and dry biomass in oat	Xun et al. (2015)
Burkholderia phytofirmans	---------	Reduces metals stress (Zn, Pb), growth promotion of crops in maize	Touceda-González et al. (2015)

MODE OF ACTION

PGPB and AMF act through complex mechanisms (Fig. 1). Majeed *et al*. (2018b) comprehensively described the plant growth promotion activities of these microbes. They argued that PGPB directly facilitates the growth and developmental processes of plants by producing vitamins, hormones, soluble nutrients etc. while indirectly by hindering the pathogens' growth. Glick (2012) asserted that different PGPB strains fix nitrogen, mobilize iron and phosphate and contribute to direct growth enhancement of plants. Souza *et al*. (2015) also provided similar arguments, stating that nitrogen fixation, siderophore production and release of organic nutrient improve plant health directly while disease suppression by the PGPB indirectly contributes to the better growth of host plants. Other roles of PGPB in the enhancement of plants include removal of heavy metals, reducing salinity and drought stress and wide spectrum biological activities (Majeed *et al*., 2018b). Sengupta and Gunri (2015) elucidated the uses of beneficial microbes and mycorhizal fungi in sustainable agriculture. They outlined that the beneficial microbes (PGPB and AMF, VMF) contributes to soil fertility by fixing nitrogen, producing siderophores, improves nutrient uptake by plants, produce hormones, improves nodulation, and provide protection to crops against plant pathogens.

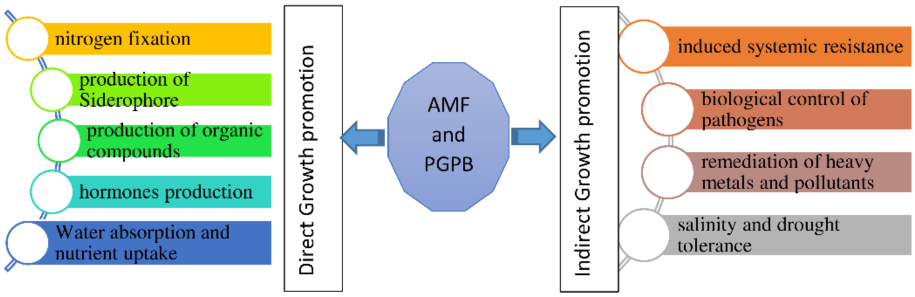

Fig. 1. Mechanism of plant growth promotion by AMF and PGPB

APPLICATIONS

PGPB found in soil generally show auto-responses to harsh conditions imposed on the host plants. In agriculture, their use is still not encouraging. Potent application of such microbes can be widely adapted as biological fertilizers and inoculation in fields. However, in a recent review, Majeed *et al*.(2018b) stated that although under laboratory studies PGPB yields good results in direct and indirect growth promotion of plants, in fields, however, their role is not yet consistent. Thus extensive gap exists in full application and a commercial formulation of PGPB as growth promoters. Economic costs and identification of suitable strains remain other hurdles in the practical applications of PGPB as plant growth promoting agents on a commercial scale.

CONCLUSION

Arbuscular mycorhizae fungi and plant growth promoting bacteria are beneficial microbes in the soil which provide assistance to plants in many ways. Directly they are concerned with hormones and organic compounds synthesis while indirectly they reduce heavy metal stress, salinity stress and diseases pressures. They can be employed in agriculture as biofertilizers, still some challenges such as the economic costs and non-durability of the microbes are present which reduces their maximum utilization in agriculture. In order to make the maximum use of these microbes in agriculture, extensive efforts are required to understand the mechanisms and interaction potentials of the microbes with diverse crops. This would lead to employment of non-symbiotic PGPB and AMF to extended range of plants. Efforts are also necessary to address the costs associated with the utilization of PGPB and AMF for reducing the use of fertilizers and pesticides.

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CONFLICT OF INTEREST

The authors declare that no competing interests exist.

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