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Short Communication

Stress-Adaptive Microbes for Plant Growth Promotion and Alleviation of Drought Stress in Plants

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Abstract

Drought is one of the major abiotic stresses accepted as the main constraint for loss of the crop yield worldwide. Further, problems are created by nutrient limitations and particularly low phosphorus (P) soil status due to which modern agricultural systems are highly dependent on chemical fertilizers. The biotechnology offers a number of sustainable solutions to mitigate these problems by using plant growth promoting (PGP) microbes. These microbes help the crops to tolerate drought conditions by different mechanisms including the production of the exopolysaccharides (EPS), phytohormones (Auxin, Gibberrellic acid and Cytokinin), 1-aminocyclopropane- 1-carboxylate (ACC) deaminase, solubilization of phosphorus, potassium and zinc, biological nitrogen fixation and enhancement of nutrient uptake, induction of the accumulation of osmolytes, antioxidants, upregulation or down regulation of the stress responsive genes. Inoculating plants with PGP microbes can increase tolerance against abiotic stresses such as drought, salinity and metal toxicity. The PGP microbes play important role in plant growth and soil health, which belong to diverse genera *Arthrobacter, Azospirillum, Azotobacter, Bacillus, Burkholderia, Enterobacter, Klebsiella, Lysinibacillus, Paenibacillus, Pseudomonas, Serratia*, and *Streptomyces*.

Keywords: Alleviation; Diversity; Drought Stress; Plant Growth Promotion; Stress-Adaptive Microbes

Introduction

There are number factors leading to the food crisis all over the world such as increasing urbanization and industrialization has led to the shrinkage of the land in past few decades. Increasing human population has further added to the world's food security concern and these factors are affecting the climate in a severe way. Additionally, the use of the chemical fertilizers is also affecting the environment. The pressure of population is increasing with such an alarming rate that there is a critical need to enhance the agricultural productivity in an eco-friendly manner. Agriculture is one of the most exposed sectors to various climatic changes. One of the major hurdle to increase the yield and productivity is exposure of the crops to the drought conditions in different parts of the world [1-5]. The drought is one of the major abiotic stresses acting as the limiting factor affecting the agricultural productivity worldwide. It has been estimated that there is approximately 9 - 10% reduction in the national production of the cereals due to the drought conditions [6].

Plant-associated beneficial microbes are recently attaining greater attention as they play an important role in enhancing the productivity of the crops and also providing resistance against the stress conditions and are known as plant growth promoting microbes (PGPMs) [7,8]. The PGPMs contribute to mitigate the stress conditions by diverse mechanisms [9,10]. The PGPMs directly enhancing the uptake of the micronutrients, through phytohormones production; fixing of atmospheric nitrogen; P, K, and Zn-solubilization or indirectly stimulating the immune system against various fungal pathogens by production of various compounds, enzymes, siderophores, antibiotics, osmolytes or improving either texture or structure of the soil [11].

Phosphorus (P) is the major macronutrient which is required by the plants for their various metabolic processes including energy transfer, signal transduction, macro-molecular biosynthesis, photosynthesis and respiration but is simultaneously the major limiting mineral nutrient for the growth of the plants due to its least availability as well as the least mobility. The replacement of soil P reserves through chemical fertilization is common, but long-term practice. There are many studies which have reported that beneficial microbes are efficient in solubilizing nutrients from soil [12-19]. The solubilization of inorganic insoluble phosphate salts by microbes result in the production or release of organic acid and organic acid decreases the pH [20-22]. The major P-solubilizers belong to genera *Achromobacter, Acinetobacter, Agrobacterium, Arthrobacter, Aspergillus, Azospirillum, Azotobacter, Bacillus, Enterobacter, Erwinia, Flavobacterium, Haloarcula, Halobacterium, Halococcus, Micrococcus, Mycobacterium, Penicillium, Pseudomonas, Rhizobium* and *Serratia* [21,23-27,28-31]. Various mechanisms used by P- solubilizers to convert the insoluble forms of the phosphorus into the soluble forms consist of acidification, chelation, exchange reactions and production of organic acids [22,32].

Another important role of plant growth promoting rhizobacteria is the synthesis of various phytohormones (plant growth regulators). The well-known phytohormones includes auxins most common being the indole acetic acid, cytokinins, gibberellins. There are diverse bacterial genera such as *Acinetobacter, Arthrobacter, Bacillus, Corynebacterium, Delftia, Duganella, Exiguobacterium, Kocuria, Lysinibacillus, Methylobacterium, Micrococcus, Micrococcus, Paenibacillus, Paenibacillus, Pantoea, Pseudomonas, Psychrobacter, Serratia* and *Stenotrophomonas* has been reported to produced diverse group of phytohormones [33-40]. Iron is one of the most vital elements important for the growth of all living organisms. It acts as the cofactor for different enzymes, it is involved in process of photosynthesis, respiration, nitrogen fixation and its deficiency leads to various metabolic alterations [41]. Iron is present in abundance in the soil but is not available for the plants as well as the microbes present in the soil as the oxidized form of the iron which is Fe^{3+} reacts forming oxides and hydroxides which is not accessible to the plants as well as the microbes. Under such iron limiting conditions PGPR have the capacity to produce low molecular weight iron chelating compounds called as the siderophores for the acquisition of the ferric ions [42].

Microbe-mediated drought stress

The elucidation of the various mechanisms by which plants respond to drought stress is very important that stress tolerant plants could be grown. This process is very complex as it involves various factors which are affecting and at the same time the factors which are affected. During drought the availability of the nutrients is also affected, and this can be overcome by the use of the plant growth promoting microbes [43-45]. Ethylene when present at high concentration proves to be inhibitory for the growth of the plants. But, PGP microbes possess an enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase enzyme which converts ACC, the immediate precursor of ethylene to α-ketobutyrate and ammonium thus lowering the concentration of the ethylene during the stress conditions and stimulating the growth of the plants. ACC deaminase activity has been reported in *Achromobacter xylosoxidans, Agrobacterium genomovars, Alcaligenes, Azospirillum lipoferum, Bacillus licheniformis, Brachybacterium saurashtrense, Brevibacterium casei, Brevibacterium iodinum, Burkholderia phytofirmins, Cronobacter sakazakii, Enterobacter cloacae, Methylobacterium fujisawaense, Pseudomonas putida, Pyrococcus horikoshii, Ralstonia solanacearum, Rhizobium leguminosarum, Rhodococcus, Sinorhizobium meliloti, Variovorax paradoxus* and *Zhihengliuela alba* [46-52]. Production of the exopolysaccharides (EPS) by PGP microbes plays a vital role in influencing the soil structure. EPS producing microbes stimulate the water binding capacity of soil and help in regulation of supply of nutrients and water to roots. EPS help in irreversible attachment colonization of the microbes to the roots due to network of fibrillar material that permanently connects the microbes to the root surfaces. Bashan., *et al.* [53], demonstrated the role of polysaccharides producing *Azospirillum* in aggregation of the soil. The production of the extracellular biofilms by PGP microbes for binding and making the water molecules in the rhizospheric region available is another strategy for alleviation of the water stress conditions [54]. EPS production has been reported in *Pseudomonas aeruginosa, Bacillus subtilis* and *Streptococcus mutans* [55].

Another important consequence of the drought is stimulation of the production of various reactive oxygen species (ROS) including hydrogen peroxide (H_2O_2), singlet oxygen ($^1O_2$), superoxide radical (O^{2-}), and the hydroxyl radical (HO-) [56] and these reactive oxygen species decreases the normal, metabolic processes of the plants by causing a oxidative damage to the lipids, various proteins ultimately leading to the cell death [57,58]. Plants possess certain enzymatic and non-enzymatic oxidants which are also referred to as the scavenging enzymes which play an efficient and supportive role to overcome the negative effects of the drought [56]. Superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), glutathione reductase (GR), and ascorbate peroxidase (APX) are among the most important enzymatic antioxidants [56-59].

Conclusion and Future Scope

The improvement of the stress tolerance and productivity of the crops is the major goal of agriculture. PGP microbes is an emerging field of science which is proving its potential helping the plants to combat with the abiotic stresses by different mechanisms including production of the phytohormones, solubilization of phosphorus, production of ACC deaminase, production of siderophores. Plant growth-promoting microbe can affect plant growth directly or indirectly. The direct promotion of plant growth by PGP microbes, for the most part, entails providing the plant with a compound that is synthesized by the bacterium or facilitating the uptake of certain nutrients from the environment. The indirect promotion of plant growth occurs when PGP microbes decrease or prevent the deleterious effects of one or more phytopathogenic organisms. Future research in microbes will rely on the development of molecular and biotechnological approaches to increase our knowledge of microbes and to achieve an integrated management of microbial populations of microbial community.

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