



## Enhancement of drought stress tolerance in crops by plant growth promoting rhizobacteria



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### ABSTRACT

Drought is one of the major constraints on agricultural productivity worldwide and is likely to further increase. Several adaptations and mitigation strategies are required to cope with drought stress. Plant growth promoting rhizobacteria (PGPR) could play a significant role in alleviation of drought stress in plants. These beneficial microorganisms colonize the rhizosphere/endo-rhizosphere of plants and impart drought tolerance by producing exopolysaccharides (EPS), phytohormones, 1-aminocyclopropane-1-carboxylate (ACC) deaminase, volatile compounds, inducing accumulation of osmolytes, antioxidants, upregulation or down regulation of stress responsive genes and alteration in root morphology in acquisition of drought tolerance. The term Induced Systemic Tolerance (IST) was coined for physical and chemical changes induced by microorganisms in plants which results in enhanced tolerance to drought stresses. In the present review we elaborate on the role of PGPR in helping plants to cope with drought stress.

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**Abbreviations:** PGPR, plant growth promoting rhizobacteria; PGPB, plant growth promoting bacteria; EPS, exopolysaccharides; ACC, 1-aminocyclopropane-1-carboxylate; IST, induced systemic tolerance; ROS, reactive oxygen species; NR, nitrate reductase; ABA, abscisic acid; IAA, indole-3-acetic acid; ACS, 1-aminocyclopropane-1-carboxylate synthase; S-AdoMet, S-adenosylmethionine; PSB, phosphate solubilising bacteria; GB, glycine betine; RWC, relative water content; DMW, dry mater weight; LP, lipopolysaccharide–protein; PL, polysaccharide–lipid; RAS/RT, root adhering soil per root tissue; O<sub>2</sub><sup>•−</sup>, superoxide anion radicals; H<sub>2</sub>O<sub>2</sub>, hydrogen peroxide; OH, hydroxyl radicals; <sup>1</sup>O<sub>2</sub>, singlet oxygen; RO, alkoxy radicals; SOD, superoxide dismutase; CAT, catalase; APX, ascorbate peroxidase; GR, glutathione reductase; GPX, glutathione peroxidase; MDA, malondialdehyde; ERD15, early response to dehydration 15; 2D-PAGE, 2-D polyacrylamide gel electrophoresis; DD-PCR, differential display polymerase chain reaction; RT-PCR, real-time PCR; AM, arbuscular mycorrhizal; Rubisco, ribulose-1,5-bisphosphate carboxy/oxygenase; PGP, plant growth promoting.

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## 1. Introduction

Drought stress is among the most destructive abiotic stresses that increased in intensity over the past decades affecting world's food security. Drought stress may range from moderate and short to extremely severe and prolonged duration, restricting the crop yields (Austin, 1989; Pereira and Chaves, 1993, 1995; Bottner et al., 1995). Drought is expected to cause serious plant growth problems for more than 50% of the arable lands by 2050 (Ashraf, 1994; Vinocur and Altman, 2005; Kasim et al., 2013).

### 1.1. Effect of drought stress on plant growth and development

Drought affects plant–water potential and turgor, enough to interfere with normal functions (Hsiao 2000) changing physiological and morphological traits in plants (Rahdari and Hoseini, 2012). Growth reduction under drought stress has been studied in several crops such as barley (Samarah, 2005), maize (Kamara et al., 2003), rice (Lafitte et al., 2007) and wheat (Rampino et al., 2006). Fresh weight and water content are common growth parameters that are affected by drought (Jaleel et al., 2009). Furthermore, drought stress influences the availability and transport of soil nutrients, as nutrients are carried to the roots by water. Drought stress therefore decreases nutrient diffusion and mass flow of water-soluble nutrients such as nitrate, sulfate, Ca, Mg, and Si (Barber, 1995; Selvakumar et al., 2012). Drought also induces free radicals affecting antioxidant defenses and Reactive Oxygen Species (ROS) such as superoxide radicals, hydrogen peroxide and hydroxyl radicals resulting in oxidative stress. At high concentrations ROS can cause damage to various levels of organization (Smirnov, 1993), like initiate lipid peroxidation, membrane deterioration and degrade proteins, lipids and nucleic acids in plants (Hendry, 2005; Sgherri et al., 2000; Nair et al., 2008). Nevertheless, under drought stress the decrease in chlorophyll content was symptom of photooxidation (Anjum et al., 2011; Rahdari et al., 2012). Decreasing of chlorophyll content in *Paulownia imperialis* (Astorga and Melendez, 2010), bean (Beinsan et al., 2003) and *Carthamus tinctorius* (Siddiqi et al., 2009) was observed under drought stress. Drought also affects biochemical activities like nitrate reductase (NR), due to lower uptake of nitrate from the soil (Caravaca et al., 2005). It also accentuates the biosynthesis of ethylene, which inhibits plant growth through several mechanisms (Ali et al., 2014). Drought as a multidimensional stress, affects at various sub cellular compartment, cell organs and whole plant level (Choluj et al., 2004; Rahdari et al., 2012). Thus drought negatively affects quantity and quality of growth in plants. Therefore, in order to produce more food, the mitigation of drought stresses is important to achieve the designated goals.

Worldwide extensive research is being carried out to develop strategies to cope with drought stress through development of drought tolerant varieties, shifting the crop calendars, resource management practices etc. (Venkateswarlu and Shanker, 2009) and most of these technologies are cost-intensive. Recent studies indicate that microorganisms can also help plants to cope with drought stress.

### 1.2. Drought stress microbial ecology

Millions of microbes inhabit plant root system forming a complex ecological community that influences plant growth and

productivity through its metabolic activities and plant interactions (Berg, 2009; Lugtenberg and Kamilova, 2009; Schmidt et al., 2014). Changes in the structure of plant-associated bacterial communities in the root zone towards the selection of assemblages that are adapted to abiotic stress, improve the resistance against stressors to promote health and drought tolerance of plants (Schmidt et al., 2014; Cherif et al., 2015). Variation in the distribution of bacteria was observed at endosphere, rhizosphere and the root surrounding soil compared to uncultivated soil associated with drought-sensitive pepper plant under desert farming conditions (*Capsicum annum* L.) indicating a selective pressure determined by the plant activity on the structure of microbiome (Marasco et al., 2012). In a similar study, pepper plants inoculated with bacterial isolates from deserts exhibited a higher tolerance to water shortage, compared with control. Inoculation enhanced the root system (up to 40%), which improved plant ability to uptake water (Marasco et al., 2013). This study provides initial evidence that the nature of the interaction has limited level of specificity and that plant growth promoting bacteria (PGPB) determine resistance to water stress in plants others than the original isolation (Marasco et al., 2013). Bacterial microbiome of *Salicornia* plants grown under hypersaline ecosystems in Tunisia showed resistance to a wide set of abiotic stresses and were able to perform different plant growth promoting (PGP) activities and higher root colonization suggesting that the halophilic/halotolerant bacteria inhabiting salty and arid ecosystems have a potential to promote plant growth under salinity and drought condition (Mapelli et al., 2013).

Microbial communities below the ground level influence the selection on plant traits by mitigating the effects of abiotic stress on plant populations (Lau and Lennon, 2011). Manipulation of below-ground microbial communities showed that *Brassica rapa* grown in soils with simplified microbial communities were smaller, with reduced chlorophyll content, fewer flowers, and less fecund when compared with plant populations grown in association with more complex soil microbial communities (Lau and Lennon, 2011). Chamomile seedlings inoculated with three indigenous Gram-positive strains (*S. subtritus* Wbn2-11, *B. subtilis* Co1-6, *P. polymyxa* Mc5Re-14) from Egypt and three Gram-negative strains (*P. fluorescens* L13-6-12, *S. rhizophila* P69, *S. plymuthica* 3Re4-18) from Europe revealed significant differences in the bacterial community structure. These differences clearly show a shift within the community structure. Moreover, *B. subtilis* Co1-6 and *P. polymyxa* Mc5Re-14 showed an enhancement of the bioactive secondary metabolite apigenin-7-O-glucoside. Inoculation of *Pseudomonas* sp. strain AKM-P6 and *P. putida* strain AKM-P7 enhanced the tolerance of sorghum and wheat seedlings to high temperature stress due to the synthesis of high-molecular weight proteins and also improved the levels of cellular metabolites (Ali et al., 2009, 2011). Hence, these studies indicate a new function of bacterial inoculants to interact with the plant microbiome as well as to influence the plant metabolome (Schmidt et al., 2014). Microbial diversity studies in native Egyptian desert soil in comparison to the agricultural soil, which was used more than 30 years for organic agriculture showed a significant difference in microbial community. *Bacillus*, *Paenibacillus* and Firmicutes were higher in field in comparison to desert soil but *Streptomyces* were antagonists from desert soil. On the other hand, several extremophilic bacteria disappeared from the soil after agricultural use. Bacterial communities in agricultural soil showed a higher diversity and a better ecosystem function for

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