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Review

Interaction of plant growth promoting bacteria with tomato under abiotic stress: A review

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ABSTRACT

Tomato is one of the most demanding/utilizable vegetable crops worldwide after potato. It is extensively cultivated throughout the tropics and sub-tropics around the world. However, certain climate change consequences like salinity, drought, and environmental pollutants particularly heavy metals etc., lead to low soil productivity. In fact, problem of salinity, drought and soil contamination are increasing rapidly throughout the globe and severely affecting more than 10% of arable land resulting into reduction of more than 50% average yields of major crops including tomato. Therefore, sustainable agriculture is in great demand under current alarming condition of food security. Plant growth promoting bacteria (PGPB) has been evident as a co-evolution between plants and microbes showing antagonistic and synergistic interactions. Therefore, utilization of PGPB to tackle the problem of salinity, drought and heavy metal contamination is one of the novel biological approaches for sustainable agriculture practices. Under stress conditions, plant hormone like ethylene is known to endogenously regulate the homeostasis of plants leading to significant reduction in root and shoot growth. Few PGPB like *Pseudomonas* sp. and *Bacillus* sp. have developed tolerance mechanism against varieties of heavy metals through mobilization, surface complexation, biosorption, precipitation, intracellular compartmentalization or immobilization processes. Looking into the multiple applications of PGPB in sustainable agriculture, scientists and policy makers are currently emphasizing over selection of suitable microbial communities through interdisciplinary research disciplines including agriculture, biotechnology, chemical engineering, environmental science and nanotechnology to bring together different ecological and functional biological approaches to provide new formulations and opportunities with immense potential. The present review entails the overview of current trends in PGPB mediated abiotic stress amelioration in order to encounter the negative impacts of changing climatic conditions for sustainable enhancement in tomato productivity.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is the world's most cultivated solanaceous vegetable crop next to potato (Pedro and Ferreira, 2005). In 2013, global production of tomato was approximately 164 million tones which cover an area of 4.8 million hectares with 7th rank in productivity (FAOSTAT, 2013; Luna et al., 2016). Currently, more than 3000 species of tomato are reported worldwide. *Solanum lycopersicum* (L.) is the most common species in its occurrence and domestication. The tomato can be consumed in raw as well as in industrially processed form like pulp and sauces. Tomato is considered as a good source of dietary minerals, vitamins (vitamins C and E), lycopene (80%), folic acid, flavonoids, β-carotene and potassium ions (Willcox et al., 2003). In addition, few organic acids of nutritional importance like (malic acid, ascorbic acid, citric acid) and trace elements (such as iron, zinc, copper, calcium, potassium and magnesium) are also reported as essential ingredients of tomato.

Tomato contains different types of pigments including lycopene (a non-provitamin A), one of the major constituents responsible for remarkable antioxidant activity that helps in reduction of risks of cancer and heart diseases (Rao and Agarwal, 1999). Most of the lycopene content in food items is derived from tomato followed by other sources like watermelon, guava and pink grape fruit (Lin and Chen, 2003; Levy and Sharoni, 2004). Currently, worldwide productivity of tomato is facing the challenges of biotic and abiotic stress factors. Drought and salinity are the two leading environmental stresses in agriculture that limits the global productivity of major crops directly by reducing the growth and yields (Cuartero et al., 2006; Nuruddin et al., 2003; Kaushal

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and Wani, 2016a,b). Apart from these stresses, presence of toxic heavy metals and/or metalloids in the agro-ecosystem is also one of the important factors limiting the crop productivity (Oztürk, 2007). Rapid industrialization and population expansion are the major factors responsible for generation of enormous amount of toxic and hazardous metals in soil environment of both developed and developing countries. Soil acts as the major sink for different heavy metals including Fe, Mn, Pb, Cd, and Cr. Heavy metals in environment are released by natural (geogenic) as well as anthropogenic activities (wastewater irrigation, industrial effluents, chemical pesticides). Unlike organic contaminants, heavy metals do not undergo microbial or chemical degradation (Kirpichtchikova et al., 2006), rendering their long term persistence in soil environment (Adriano, 2003). Large amount discharge of noxious heavy metals into agricultural fields causes metal accumulation thus, food chain contamination (Costa and Duta, 2001) beyond the prescribed safety limits in cultivated crops causing hazardous impact on human health (Li et al., 2006).

It is well known that high concentration of different heavy metals affects the natural environments and human beings directly or indirectly through various ways (Srivastava et al., 2012; Wilson and Pyatt, 2007). Growth and yield of plant is severely affected by high content of soil heavy metals, resulting from application of various fertilizers, pesticides, irrigation with sewage water and sludge addition in cultivable fields (Frost and Ketchum, 2000). Contamination of heavy metals in soil depends on quantity and nature of pesticides used in soil, level of emission and transport of heavy metals from nearby sources including industries and mining sites. Micronutrients like Mn, Fe, Zn, Cu, Ni and Co are essential for growth of plants, animals and microorganisms in low concentrations, while elements like Cd, Hg and Pb have no essential role in the vital biological activities (Ali et al., 2013). Being highly toxic even at very low concentrations (Gadd, 1992), the elevated concentration of such metals above threshold levels in soils as well as the long term persistence of potentially toxic heavy metals (e.g., Cd and Pb) and metalloids (e.g., As) in agricultural field may adversely influence the physico-chemical and biological properties of soil in a quantitative as well as qualitative manner (Ahemad, 2012, 2014).

In addition, presence of xenobiotics such as organic compounds particularly polycyclic aromatic hydrocarbons (PAHs) have long been reported to pose threat to agro-ecosystems thus, severely affecting the crop plant productivity as well as human health (Fine et al., 1997; Overcash and Pal, 1979). The PAHs are a group of complex organic chemicals having more than hundred different organic compounds which are generated by incomplete combustion of organic matters, forest fires, traffic, household heating and waste incineration (Johnsen et al., 2005). Their wide distribution and long term persistence in soil and water environment largely depends on physical and chemical characteristics of PAHs.

Application of plant growth promoting bacteria (PGPB) to alleviate the negative impacts of environmental stresses is a cost effective and eco-friendly biological approach as compared to physico-chemical methodologies currently being applied. During last two decades, many research groups have broadly used PGPB strains to enhance growth and yields of plants under environmental stress (Bacilio et al., 2004; Sessitsch et al., 2013; Kumar et al., 2014; Ji et al., 2014; Mayak et al., 2004a, b; Rolli et al., 2015; Timmusk et al., 2015; Zahid et al., 2015). Besides stress management, PGPB also serve as biocontrol, bio-fertilizer or phyto-stimulator, which helps in soil fertility maintenance by removing heavy metals and other soil contaminants, thereby acting as a promising alternative to indiscriminately used hazardous chemical fertilizers for sustainable agriculture (Fig. 1) (Kloepper et al., 2004a,b; Glick, 2014; Majeed et al., 2015; Singh et al., 2017a,b; Dal Cortivo et al., 2017). Therefore, in present review we have attempted to provide an overview of role of PGPB in abiotic stress amelioration for enhanced tomato productivity.

2. Role of plant growth promoting bacteria (PGPB) in plant growth and development

Term rhizosphere designates to plant roots and surrounding soil (a thin layer of soil adhered to the plant root surface) and is the most prominent zone responsible for diverse microbial interactions (Kumar et al., 2015). Various level of interactions are favored by plant's root due to synthesis and secretion of large amount of carbohydrates, lipids, organic acids, and amino acids as root exudates favoring the interaction of diverse microbial communities in rhizosphere which facilitates effective microbial colonization (Brimecombe et al., 2007; Oku et al., 2012; Kumar et al., 2015). Root exudates of tomato includes various biochemical components like amino acids (glutamic acid, aspartic acid, leucine, isoleucine, and lysine), organic acids (citric acid, malic acid, and succinic acid), and sugars (glucose, xylose) (Kamilova et al., 2006; Oku et al., 2012; Singh et al., 2017a,b). The components of root exudates are known to effectively participate in microbial colonization of tomato root and essentially involved in biocontrol of root pathogens (Suslow et al., 1982). Plant growth in soil environment is markedly influenced by many abiotic and biotic factors including microbes (Singh, 2015). Bacteria are the most abundant group of microorganisms coexisting with fungi, actinomycetes, protozoa and algae in the rhizosphere. Due to dominance of bacterial population in the rhizosphere, their influence on plant physiological processes is highly anticipated (Barriuso et al., 2008). Hayat et al. (2010) reported that the rhizospheric bacteria are the most versatile in transforming, mobilizing, and solubilizing the nutrients compared to bulk soils. Microorganisms colonizing the rhizosphere can be classified according to type of interactions with plants; some may act as pathogens, whereas others may trigger beneficial interactions such as growth promotion and metabolite synthesis in host plants (Kumar et al., 2017a,b). In past decades, exploration and identification of PGPB attributes (siderophore production, antibiotic production, biocontrol, etc.) have received tremendous momentum because of their participation and contribution in the rhizosphere functions (plant growth promotion, bio-geochemical cycling, plant protection against pathogens, etc.). Some of the outstanding examples of plant growth promoting bacteria (PGPB) are *Alcaligenes*, *Arthrobacter*, *Azotobacter*, *Bacillus*, *Burkholderia*, *Enterobacter*, *Klebsiella*, and *Pseudomonas* (Mellado et al., 2007; Lee et al., 2016; Hammami et al., 2013). These PGPBs have been employed as plant or soil inoculants for growth promotion and yield enhancement in plants as well as to maintain soil productivity and nutrient availability.

3. PGPB mediated growth and yield enhancement in tomato

Plant growth promoting bacteria (PGPB) are one of the most promising organisms for growth and yield enhancement in different plants species including tomato. Ribaudo et al. (2006) reported beneficial interaction of *Azospirillum brasilens* FT326 with tomato plants. Tomato seed inoculation with nitrogen fixing *Azospirillum brasilens* FT326 was observed to significantly enhance the root and shoot weight as well as length of root hairs, which may be due to higher amount secretions of important phytohormone *i.e.* indole-3-acetic acid (IAA) and ethylene. Surface bacterization of tomato, groundnut, sorghum and chickpea with the bacteria (isolated from rhizoplane, rhizosphere and phylloplane region of tomato) resulted into positive growth response only in case of tomato while neutral or negative effects were observed for groundnut, sorghum and chickpea. The study concluded that bacteria with plant growth promoting traits did not positively influence the growth of all selected plants; they may perform host specificity (Vaikuntapu et al., 2014). Other researchers have also reported the similar plant growth promoting effect induced by well known PGPB *Pseudomonas fluorescens* (Gupta et al., 2015). Under green house conditions, different PGPB combinations were found to pose different effects. Increase in root and shoot weight with increased absorption of mineral elements like N, P, K, Ca and Mg were noticed under altered

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