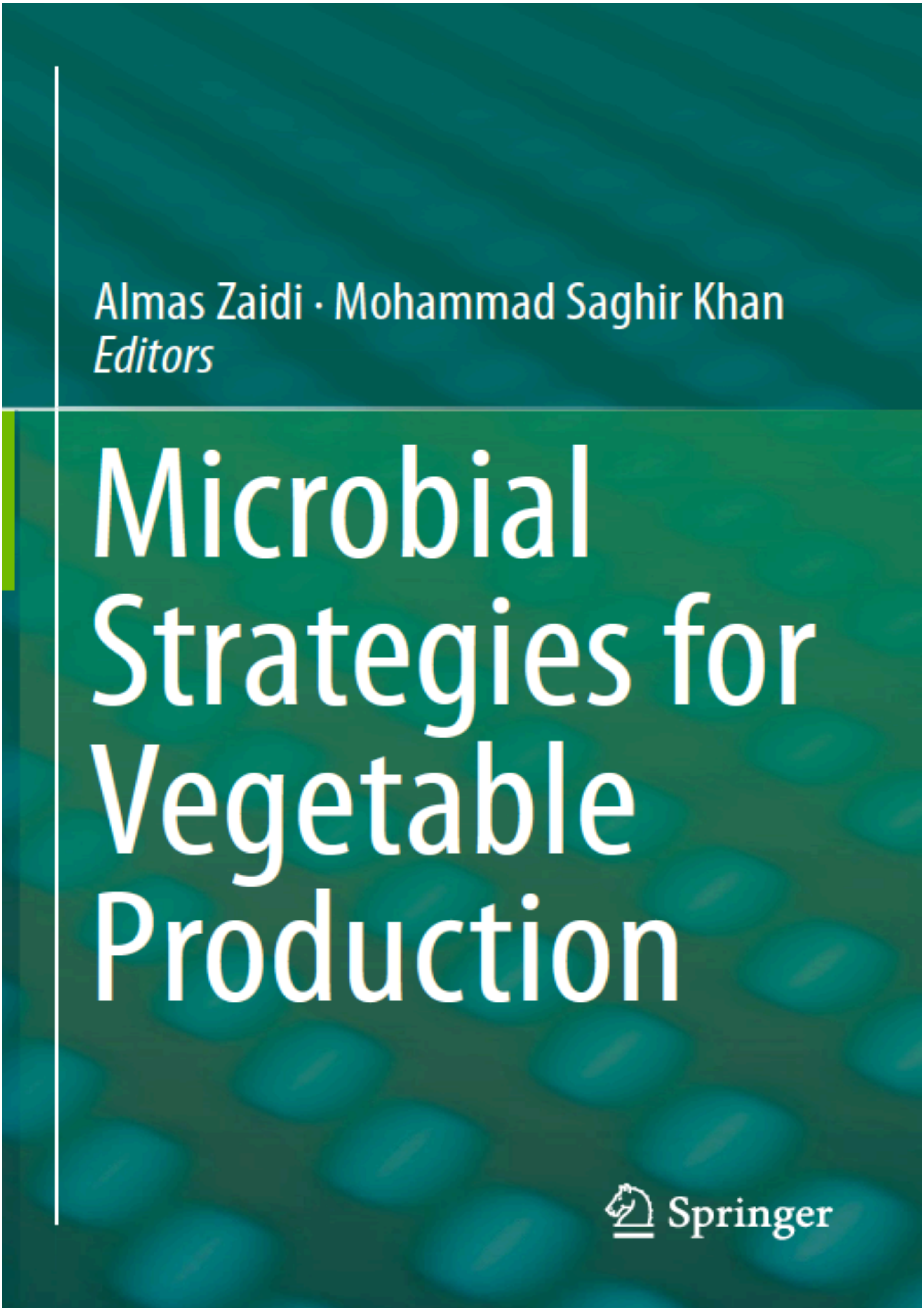

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Beneficial Role of Plant Growth-Promoting Bacteria in Vegetable Production Under Abiotic Stress

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Abstract

Changes in climate, natural or man induced, urbanization and several other factors result in abiotic stress, for example, high winds, extreme temperatures, drought, flood, etc. Such factors in turn affect many plants including vegetables. Vegetables, being plants grown for their vegetative parts, are, however, more sensitive to abiotic stress, when compared to grass family. The abiotic stress limits soil/climate for vegetable plantation and consequently results in decreased vegetable yields. Plant growth-promoting bacteria (PGPB) are beneficial soil bacteria capable of stimulating physical, chemical and biological changes in plants. In particular, for vegetables, there are numerous applications of these beneficial microorganisms to alleviate the adverse effects of abiotic stress. This review focuses on alternative mechanisms employed by PGPB to enhance vegetable production under various abiotic stresses, including drought, salinity, extreme temperature, nutrient and heavy metal stresses.

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7.1 Introduction

Nutritional status, physical and biological properties of soil, constantly changing climate and other abiotic stresses are the primary causes for reduced agricultural productivity (Gopalakrishnan et al. 2015). Especially, abiotic stresses are the main reason for crop yield losses and food price increase in the world with growing population. The growth of plants in the field may be hampered by a large number of environmental abiotic stresses. These stresses include high and low temperature, drought, toxic metals, environmental organic contaminants and salinity (Glick et al. 2007). In addition to these stresses, climate change limits the geographical distribution and agricultural productivity of crops causing dramatic losses especially to vegetable species in several parts of the world (Olesen and Bindi 2002). Efforts to develop stress-tolerant vegetables via conventional breeding or transgenic approaches are challenging in itself since multiple genes and metabolic processes are involved in stress tolerance (Ashraf and Akram 2009). Apart from scientific and technical limitations, most of these techniques are time-consuming, cost intensive and not well accepted. Therefore, alternative approaches that would be affordable, eco-friendly and well accepted by the public need to be considered. A different approach to induce stress tolerance is the use of beneficial bacteria. Among variously distributed microbiota, the use of beneficial bacteria such as plant growth-promoting bacteria (PGPB or PGPR, henceforth denoted with the first one) has recently emerged as a potential new solution to protect crops against damages caused by abiotic stresses (Palaniyandi et al. 2014; Fatnassi et al. 2015; Wang et al. 2016).

Plant growth-promoting bacteria are beneficial soil bacteria capable of stimulating physical, chemical and biological changes in vegetables (Adesemoye et al. 2008), resulting both directly and indirectly in enhanced plant tolerance to abiotic stresses (Glick et al. 2007). Direct stimulation may include providing phytohormones to plants (Cassán et al. 2014), iron that has been sequestered by bacterial siderophores (Wandersman and Delepelaire 2004), soluble phosphate (Oteino et al. 2015) and fixing-free nitrogen (Santi et al. 2013; Yildirim et al. 2015), while indirect stimulation of plant growth includes preventing phytopathogens (biocontrol) and, thus, promotes plant growth and development (Glick and Bashan 1997). Particularly, production of ethylene in response to abiotic stresses leads to inhibition of root growth of the vegetables (Abeles et al. 2012). PGPR facing abiotic stress conditions regulate precipitated ethylene; examples are reported in several studies (Chen et al. 2013; Siddikee et al. 2012). Many of the studies have reported that PGPB strains improve the N_2 fixation (Nadeem et al. 2014; Gupta et al. 2014) and survive under stressed soil conditions, and when compared with agrochemicals, they have been found to be safe, inexpensive and rhizosphere competent.

Vegetables are plants grown for their vegetative parts, like leaves, fruits or stems. Vegetables consist of several plant families, grouped according to the plant organs: leafy vegetables (e.g. lettuce, spinach), stem vegetables (e.g. celery, asparagus), root vegetables (e.g. potatoes, carrots), legumes and pulses (e.g. beans, peas, lentils), crucifer family (*Brassicas*, e.g. cabbage, cauliflower, Brussel sprouts), *Allium* family (bulb vegetables, e.g. onion, garlic), fruiting vegetables (botanical fruits, e.g. pumpkin, cucumber, tomato, zucchini), mushrooms and fungi. Vegetables contain vitamins, carbohydrates, salts and proteins, important for human nutrition. Worldwide, China, with 55% share, is the leading vegetable producer followed by India with 10.6%. Each vegetable species requires a specific growth condition where temperature, rainfall, humidity, chilling, density and length of sunlight, wind, etc. are important factors for vegetable growth. Among the horticultural plants, vegetables are especially more sensitive than the others for the extreme conditions (Schwarz et al. 2010). Temperature, moisture, soil physical characteristics, various cultural practices, disease and another stress factors can affect stand establishment in vegetable crop production (Grassbaugh and Bennett 1998).

7.2 Impact of Plant Growth-Promoting Bacteria on Vegetables Under Stressed Environment

7.2.1 Role of PGPB In Drought Stress

Drought is considered to be the most severe abiotic stress that limits growth and development of plants in arid and semiarid regions and attracts further attention considering climate-induced changes (Maybank et al. 1995). Furthermore, drought affects nearly all parts of the world (Wilhite 2000) and more than half of the earth is suffering from drought for long times (Kogan 1997). Plants respond to drought stress both at cellular and molecular levels. A well-studied response to drought is the increased level of ethylene (Singh et al. 2015). Drought accelerates ethylene production in plants leading to reduced or anomalous growth and premature senescence (Mattoo and Suttle 1991; et al. 2016; Hueso et al. 2011). PGPB promote plant growth and development under drought stress via lowering ethylene levels by hydrolyzing 1-aminocyclopropane-1-carboxylic acid (ACC), the immediate precursor of ethylene in plants (Zahir et al. 2008). Mayak et al. (2004a) reported that ACC deaminase containing *Achromobacter piechaudii* ARV8 substantially increased the fresh and dry weights of both tomato and pepper seedlings exposed to transient water stress. In most of the reported cases with increased ethylene levels due to drought, PGPB containing ACC deaminase significantly decreased ACC level in stressed plants, limiting ethylene synthesis, and hence relieved the damage to the plant. Saleem et al. (2007) reported such effect in tomato seedlings exposed to water stress. Interestingly, the review pointed that inoculation of tomato plants with the various bacteria resulted in continued plant growth both during water stress and when watering was resumed.

Similar effect of PGPB is expected in eliminating the growth-hampering effects of drought on the growth of peas (Akhtar and Azam 2014). Following this, Dodd et al. (2009) investigated the physiological responses of pea (*Pisum sativum* L.) to inoculation with ACC deaminase bacterium *Variovorax paradoxus* 5C-2 under drought stress. Within the same line, Figueiredo et al. (2008) reported an increased plant growth, N content and nodulation of common bean (*Phaseolus vulgaris* L.) even under drought due to co-inoculation of *Rhizobium tropici* and *Paenibacillus polymyxa*, leading to changes in hormone balance and stomatal conductance. During water scarcity, the bacteria did not influence the water content of plants; however, they significantly improved the recovery of plants when watering was resumed. Overall, positive effects of PGPB on plant growth parameters, e.g. chlorophyll content, trichome density, stomatal density and levels of secondary metabolites, are expected and/or reported. Indeed for peppermint, Cappellari et al. (2015) reported the application of PGPB, with the idea to illustrate the poorly known effects of PGPR on aromatic plant species. The authors measured several growth parameters and levels of secondary metabolites upon inoculation with strains of *Bacillus* and *Pseudomonas*. Also, the inoculation of PGPB has been reported to eliminate the effects of water stress on growth, yield and ripening of pea grown both under pot and field trials (Arshad et al. 2008).

7.2.2 Role of PGPB in Salinity Stress

Soil and water salinization is an important abiotic threat all over the world for agricultural production, currently affecting approximately 50% of fields, and the situation is only expected to get worse in the near future with the global climate changes. Moreover, lands facing salinity stress will also face drought due to increasing frequency of dry periods, leading to combined abiotic stresses. Salinity from soil or water has been causing significant decrease in the productiveness of many types of plants both in Turkey and in the world. Globally, 5% of the total 1.5 billion hectare land with agricultural production is affected by salinity (Tester and Davenport 2003). Salinity in the soil prevents the uptake of water (osmotic effect). Its effects on the roots, together with toxic effects of Na and Cl ions (increasing Na uptake while decreasing Ca and K uptake), are hampering plant development and productivity (Greenway and Munns 1980; Neel et al. 2002). Furthermore, it is reported that vegetables are more sensitive to salt than forages and grains (Waller and Yitayew 2016). Different methods have been adopted to obtain crops with increased tolerance to salinity stress. These methods include conventional breeding and selection, introgression with more resistant (wild) types and domesticating halophytes for the plant side and agrobiotechnological methods to handle the effect of flooding on crop production. Also, the use of PGPB to minimize salt stress on several plants has been reported (Mayak et al. 2004a; Rojas-Tapias et al. 2012; Yue et al. 2007).

All vegetables with the exception of beet and spinach are classified as either sensitive or semi-sensitive to salinity (Grattan and Grieve 1998). Similar to drought, the effects of salt stress can be reduced by the use of microorganisms that accelerate plant development (Mayak et al. 2004b). In coastal semiarid zones, the spreading of the halophyte *Salicornia bigelovii* was supported by using *Klebsiella pneumoniae* and *A. halopraeferens* as auxiliary biofertilizer combination (Rueda-Puente et al. 2004). Similarly, several PGPB such as *Rhizobium*, *Azospirillum* and mycorrhizal fungi species have been employed to inoculate crop seeds, such as lettuce, and seedlings to alleviate the salt and water stress (Barassi et al. 2006). The application of PGPB either to the seeds or environment reduces the adverse effects of salinity for eggplant (Bochow et al. 2001), tomato and pepper (Mayak et al. 2004b), beans (Yildirim and Taylor 2005), artichoke (Saleh et al. 2005), lettuce (Han and Lee 2005; Barassi et al. 2006; Sahin et al. 2015), squash (Yildirim et al. 2006), cabbage (Yildirim et al. 2015), chickpea (Elkoca et al. 2015), strawberry (İpek et al. 2014; Erdogan et al. 2016) and *Vicia pannonica* (Esringü et al. 2016). Research shows that positive effect of these bacteria results from the efficiency of water use by plants and stimulation of root development as a result of plant hormones such as auxin supplied to plants and released by these bacteria. A study carried on tomato shows that salinity negatively affects plant development, but the applications of *Streptomyces* sp. strain PGPA39 increased ACC deaminase activity and IAA production and phosphate solubilization in plants (Palaniyandi et al. 2014).

Similar to drought, an important mechanism to reduce the effect of salt stress by the use of PGPB is the reduction of ethylene synthesis, due to ACC deaminase enzyme (Mayak et al. 2004b; Sergeeva et al. 2006; Hontzeas et al. 2006). ACC deaminase is particularly useful in regulating ethylene concentration in roots (Glick 1995; Glick et al. 1999). A model has been suggested by Glick et al. (1998) to elicit the mechanism of how ACC deaminase helps to alleviate the stress conditions. The model suggests that phytohormone indole-3-acetic acid (IAA), which is one of the enzymes that is also synthesized by PGPB, can be consumed by plants. IAA not only has a contribution to the plant growth by stimulating the cell proliferation and elongation but also increases the activity of the enzyme ACC synthetase. The ACC synthetase has a role in production of ACC, an ethylene precursor. Significant amounts of the ACC synthesized by the plant are expelled into the soil. The soil microorganisms use this ACC as a nitrogen source via hydrolysis of ACC by ACC deaminase. In order to maintain the equilibrium of ACC levels inside the plant and the outside of the plant, plants secrete the ACC further into the soil. The ACC is a precursor for plant stress hormone ethylene; thus, when the ACC amount is lowered in plant's system, the ethylene production is constrained.

Salt stress was reduced in lettuce by application of *Azospirillum* (Barassi et al. 2006). It is speculated that this can be due to prevention of Na uptake and increase in the accumulation of osmolytes such as proline and glutamate (Barassi et al. 2006). Again in lettuce, it is reported that application of *Pseudomonas mendocina* in salty conditions increases plant's nutrition uptake and also ACC deaminase activity (Kohler et al. 2009). It is observed that application of PGPB like strains Mk1 of *Pseudomonas syringae*, Mk20 of *Pseudomonas fluorescens* and Mk25 of *Pseudomonas fluorescens* biotype G to mung beans subject to salt stress resulted in nodule formation and increase in ACC deaminase activity and effectiveness of water consumption (Ahmad et al. 2011, 2012). It is determined that *Rhizobium* and *Pseudomonas* strains, which play a major role in water consumption effectiveness in corns, increased proline and relative water content (RWC) levels in the leaves and facilitated uptake of K ions. Rueda-Puente et al. (2010) reported that after application of *Klebsiella pneumoniae* and *Azospirillum halopraeferens* to pepper grown under salt-stressed conditions, plant's total weight, root length and fresh and dry weight were increased. The effect of salinity stress with different salt concentration on pepper plants and alleviation of the stress with PGPB were investigated. Non-inoculated pepper plants died after 5 weeks by the time grown in the presence of high salt (120 mM NaCl); however, 80% of pepper plants inoculated with *P. fluorescens* 2112 survived under salinity stress (Lim et al. 2012). Specifically, *Azospirillum brasilense* has been reported to work well on alleviating the salinity stress on both seed germination and plant growth (Barassi et al. 2006). del Amor and Cuadra-Crespo (2012) in other investigation assessed the impact of *Azospirillum brasilense* and *Pantoea dispersa* on sweet pepper (*Capsicum annuum* L.) grown under saline stress. Plants were exposed to 0, 40, 80 and 120 mM NaCl in solution, and the effect on plant growth, leaf gas exchange, NO_3^-, Cl^-, K^+ and Na^+ accumulation and chlorophyll fluorescence and content was investigated. These results demonstrated that the benefit of these bacterial inoculants in ameliorating the deleterious effect of NaCl in a salt-sensitive vegetable as sweet pepper was apparent.

7.2.3 Role of PGPB in High Temperature

Increased CO_2 levels and other greenhouse gases are considered as major cause of global warming. It is also claimed that in the future, this effect will further be pronounced and will hamper the agricultural production (Kijne 2006). Plants react differently to the high temperature (both in soil and/or weather) during day and night. There are also substantial variations among vegetables regarding their response to varying temperature levels. Expectedly, vegetables of cool climates are more sensitive to hot weathers than vegetables of warm climates. Moreover, in vegetable production, level and duration of hot weather and plant's developmental stage play important roles in determining the level of damage (Hall 2000). Increased temperature negatively affects germination, shoot growth and nutrition uptake by vegetables and damages membrane stability. For instance, high temperature causes thermal dormancy of lettuce. During vegetative plant development period, it causes a decrease in the photosynthesis rate, carbon dioxide assimilation and metabolic activity (Al-Khatib and Paulsen 1999; Sam et al. 2001). Damages in membrane stability cause necrotic spots on the leaves similar to symptoms of drought stress and finally resulting in the death of the plant (Hall 2000). During plant generative development period, in turn, high temperature causes an important reduction in productivity by negatively affecting pollen germination, pollination, blossoming and formation of seed and fruit set (Hall 1992, 1993).

Plant growth-promoting bacteria have been reported to reduce the negative effect of heat on plants. For example, Martin and Stutz (2004) reported that isolates of *Glomus* increased dry substance quantity, positively affected the development and productivity of pepper plants and increased phosphorus uptake. Furthermore, in a similar study, *Microbacterium* M12M, *Bacillus* sp. B10M, *Pseudomonas* sp. P29M and *Pseudomonas* sp. P12M bacteria species decreased the negative effect of heat on soybean growth and productivity and increased the nutrient uptake of plants from the soil (Egamberdiyeva et al. 2004). Similar to other environmental stresses (drought and salinity), accelerated ethylene production under high temperatures has widely been reported both in plant tissues and microbial species in the rhizosphere. In order to cope with this, plants with ACC deaminase expression lower ethylene level (Timmusk and Wagner 1999). Bensalim et al. (1998) revealed that a *Burkholderia phytofirmans* strain PsJN improved the growth of potato plants by maintaining it even under high heat stress.

7.2.4 Role of PGPB in Low Temperature

Vegetables are greatly affected by the heat in the surrounding environment at all stages from seed germination to the final product. And hence, they need optimum temperature level. This optimum temperature (range) requirement varies between species and among plant varieties. Low temperature may negatively affect plant growth and consequently the productivity. It slows down the germination and shoots growth, limits the intake of nutrition and water, increases damages from the soil-borne diseases, affects negatively blooming, seed formation and ripening of fruits and finally may cause the death of the plant (Pierce 1987). Like other plants, warm climate vegetable species are even more sensitive to low temperature than the vegetables growing at temperate regions (Decoteau 2000).

Mechanistically, low temperature affects all metabolic activity of the cell due to the simple fact that enzymes work slower or inefficiently at low temperatures. Following this, low temperature may affect production of organic acids, sugars, phenolic compounds, phospholipids, protein and ATP in plants and in turn damages cell membranes (Lyons 1973). Particularly soluble sugars, as these are typical osmolytes in plants, play various roles in low-temperature tolerance. These play regulating roles similar to proline. Its accumulation is a significant metabolic adjustment by which plants exhibit low-temperature tolerance throughout cold acclimation (Janská et al. 2010; Turan et al 2012a and 2013).

Expectedly, application of PGPB relaxes the effect of low-temperature stress on vegetables such as cabbage by increasing the accumulation of osmoprotectants (e.g. proline) and hormones and the activities of antioxidants and the expression of genes that are associated with low-temperature stress tolerance (Wang et al. 2016; Bashan and Holguin 1997). These bacteria increase plant's nutrient uptake and hormone production and accumulation of starch, proline and phenolic compounds (Barka et al. 2006; Fernandez et al. 2012). Kang et al. (2015) reported that in pepper subjected to low-temperature stress and treated with PGPB *Serratia nematodiphila* PEJ1011, the level of gibberellin and abscisic acid was increased, while the level of jasmonic acid and salicylic acid did decrease. While it is observed that 15.56% of tomatoes were able to survive at 4 °C, while following *Bacillus cereus* AR156, *B. subtilis* SM21 and *Serratia* sp. XY21 application, the survival rate of tomato increased to 92.59% (Wang et al. 2016). Sun et al. (1995) reported that a possible mechanism of PGPB under low-temperature stress could be due to the release of antifreeze proteins which promote the growth of roots. It was also indicated that these bacteria, at low temperature, could increase the root length, fresh and dry weights and level of chlorophyll in the leaves, and these increases are being related to the reduction of ethylene level enzymatically (Glick et al. 1997).

7.2.5 Role of PGPB in Nutrient Stress

Another significant abiotic stress that affects the plant growth is the nutrient stress, which is indicated by decreased uptake of specific nutrients. Minerals, also called as macro- and micronutrients, are elements that directly/indirectly affect the physiological and biochemical processes of plants including vegetables. The deficiency of nutrients may slow down and even stop the vegetative and reproductive growth of plants (Gerloff 1987; Balakrishnan 1999) leading eventually to the death of the plant (Bennett 1993). However, the applications of PGPB as biofertilizer, in contrast, have been found to increase the uptake of nutrients by plants and facilitate plant growth (Calvo et al. 2015; Çakmakçi 2016). These inoculants, when applied, enhance plant growth and yield or protect plants from pests and diseases (Ramjegathesh et al. 2013). In this regard, several microbial inoculants have been used as biofertilizers, which supply nutrients like nitrogen, phosphorus, potassium, sulphur, iron, etc. to plants. The genera most commonly used as biocontrol agents are *Pseudomonas* (Tewari and Arora 2015), *Bacillus* (Alavo et al. 2015), *Burkholderia* (Pinedo et al. 2015), *Agrobacterium* (Bazzi et al. 2015), *Streptomyces* (Bhai et al. 2016; Viaene et al. 2016), etc. These organisms suppress plant disease by production of antibiotics (Prasannakumar et al. 2015) and siderophores (Patel et al. 2016; Adnan et al. 2016), by induction of systemic resistance (Zebelo et al. 2016; Annapurna et al. 2013) or any other mechanism.

Bacterial activity in the soil plays a major role in the functioning of the ecosystem since bacteria takes part in the biochemical cycle of many nutrient elements for plants. In an early work, Lin et al. (1983) reported the positive effect of PGPB in increasing the uptake of nutrients from the environment. It is found out that PGPB promote root formation and plant growth by increasing internal IAA level in the plant. Moreover, it also increases uptake of nitrogen, phosphorus and potassium under both stress and normal conditions (Singh and Singh 1993; Grichko and Glick 2001; Mayak et al. 2004b; Turan 2012b). A side, often underestimated feature is the stimulation of the ATPase proton pump to facilitate nutrient uptake. It is determined that application of *Enterobacter cloacae* CAL3 to tomatoes, peppers and beans under vermiculite environment without any nutrient medium for a period of 6–8 weeks caused an increase both in dry and fresh weights (Mayak et al. 2001). Yildirim et al. (2006) found out that bacteria belonging to *Bacillus* and *Paenibacillus* strains and fungi from *Trichoderma* strain were able to increase K and Ca uptake in squash grown under water stress. Similarly, Mayak et al. (2004b) also determined that application of PGPB increased phosphorous uptake by tomatoes grown under salt stress. Martin and Stutz (2004) found out that bacteria increased P uptake in peppers grown in high and low temperatures. Several studies report that some free-living bacteria in the rhizosphere fix free nitrogen and direct it to the use of plants

(Glick 1995; Glick et al. 1998; Sharma et al. 2003; Pii et al. 2015). Today, problems that can arise in soil as a result of excessive fertilizer application can be diminished by using PGPB in agricultural land that has been already damaged by unconscious and overdosing of fertilizers. Moreover, it could even be possible to obtain positive results by combining PGPB with the use of fertilizers at doses lower than normally prescribed for a plant. Hernández and Chailloux (2004) reported that in a greenhouse study, application of two different PGPB species supplemented with half of the normal fertilizer level resulted in increased productivity when compared with using only fertilizer.

7.2.6 Role of PGPB In Heavy Metal Stress

One of the significant environmental issues in soil is heavy metal contamination, and it has many negative effects on agricultural operations and human health. The increase in mining activities, new factories and growing industrialization contaminate large areas with heavy metals. It is reported that heavy metals become part of the food chain as they are accumulated by plants (Rubio et al. 1994). Some, but not all, metals are fundamental micronutrients required by plants for growth and development. Even if these are required, when present in excess, they may act as toxicants and suppress the growth (Ernst 1998). Those metals, which have negative effects on growth and productivity, if excessively accumulated, are cadmium, chromium, zinc, copper, lead and nickel (Prasad and Strzalka 2000; Brune and Dietz 1995). Such metals have toxic, as well as inhibitory, effects since they replace minerals that are necessary for plants such as iron by inhibiting the uptake of these. Additionally, there are public concerns about the accumulation of heavy metals present in soil, their transfer to the plants and eventual contribution of these heavy metals to the food chain (Kiziloglu et al. 2008).

Heavy metals cause reduction of chlorophyll, and, as a result, photosynthesis rate is decreased. Besides, high metal levels in the soil have also been shown to cause increased ethylene production, inhibiting, in turn, the plant development by minimizing CO_2 fixation and limiting sugar translocation (Buchanan et al. 2000). Arshad et al. (2008) reported successful application of PGPB, containing ACC deaminase activity, in phytoremediation of heavy metal polluted soil environment. Studies indicated that some plant growth-promoting bacteria decreased the negative effect of copper in beans (Fatnassi et al. 2015), zinc in potatoes (Gururani et al. 2013), cadmium in peas (Safronova et al. 2006) and nickel, lead and zinc in tomatoes, canola and Indian mustard (Burd et al. 2000). They had a protective effect and caused an increase in uptake of P, Ca and Fe. Similarly, it was also reported that ACC deaminase enzyme along with PGPB reversed and regulated the increase in ethylene levels caused by heavy metals (Grichko et al. 2000; Belimov et al. 2001; Nie et al. 2002). Vegetable growth and nutritional properties are decreased by heavy metal stress when compared to vegetables grown under normal conditions. This being said, vegetables inoculated with PGPB retained the biomass similar to healthy plants, even under metal stress. These results indicate that it is a multifunction of PGPB that can promote the growth and development of vegetables by alleviating the heavy metal stress. For example, in a study, it was focused on *Alcaligenes* sp. RZS3 and *P. aeruginosa* RZS3 producing siderophores as washing agents to clean up heavy metals from contaminated soils. It was reported that against several stress factors, different symbiotic and non-symbiotic bacteria (e.g. for symbiotics like *Rhizobium*, *Bradyrhizobium* and *Mesorhizobium* and for non-symbiotic like *Pseudomonas*, *Bacillus*, *Klebsiella*, *Azotobacter*, *Azospirillum* and *Azomonas*) were used without decreasing plant growth under these stresses (Munns et al. 2002).

Conclusion

In today's world, significant problems in agricultural production are due to abiotic stresses induced by environmental factors either in surrounding air or soil. In view of these environmental effects, especially in developed countries where vegetable production is common and much of this productivity is based on the extensive use of inexpensive chemicals and fertilizers, there is little immediate agricultural incentive. Besides these, in many of the less-developed countries of the world where vegetable growing is not as high, relatively low-cost labour and high chemical costs provide a situation where the use of plant growth-promoting bacteria provides an attractive commercial possibility. With the above-mentioned benefits, PGPB can help tolerate several abiotic stress conditions (drought, salt, heavy metals, etc.) in an affordable manner, preventing, at the same time, the excessive use of chemical fertilizers.

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