Review Article

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Abiotic stress tolerance in horticultural crops by phyto-beneficial microbial inoculants: a review

Abstract

Many agricultural crops at global level are exposed to numerous abiotic stresses such as extremely high or low temperature, salinity, drought, acidic soils, and metal toxicity. Depending on the type of crop, such abiotic stresses result in yield losses in tune of 50 to 82%. It is widely recognized that microbes perform crucial roles in biogeochemical cycling; the impact of microbes on plant productivity and diversity is still need to understand. The role of microbial inoculants in plant growth promotion, nutrient management and disease control is very well studied. These beneficial microorganisms colonize the rhizosphere / endorhizosphere of plants and promote growth of the plants through various direct and indirect mechanisms. Microorganisms could play a significant role in this respect; if suitably exploit their unique properties of tolerance to extremities. It is therefore, very essential to explore the soil microbial diversity and the various modes of actions involved in direct and indirect plant growth promotion and develop consortium of two or more phyto-beneficial microbes to attain maximum benefits from microbial inoculation. The present review article provides concise updated information on Phyto-beneficial microbial inoculants in food production system especially horticultural crops.

Keywords: abiotic stress, horticultural crops, Phyto-beneficial microbes, microbial inoculants

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Introduction

The scenario of horticulture crops has become very encouraging at global level due to crop diversification, development of new varieties and adoption of scientific production and postharvest management. India's horticulture crops output rose to a record 311 million tonne in 2017-18 year, thus surpassing the country's food grain output for the fifth straight year. Production of horticultural crops mainly, fruits, vegetables, spice and flowers by about 5 per cent per annum.[1] The country's horticultural production surpassed its food grains output during second decade of 21st century.

Similar trend of fruits, vegetables spices and other condiments production is being witnessed across the global. The increase in horticultural production is owing to realization by the policy makers about the role played by the fruits, vegetable and spices in nutritional security of the people. However, the climate change and variation in weather pattern in many places had led to devise the crop production strategies that can mitigate the adverse effects of drought, salinity and flooding. In this endeavour, management of crops through application of beneficial microbes provide dual benefit by protecting the environment from harmful chemical impacts on one side and conservation of microbial life of soil on other side.

Phyto-beneficial microbes

Soil microbes play vital role in terrestrial environment and persuade many important edaphic and atmospheric processes, including nutrient element acquisition, nitrogen cycle, carbon cycle[2] and soil creation.[3] Further, soil microflora represents the major proportion of active life in soil and has a large share of the genetic diversity on Earth. It has been reported that soil contains as many as 10^{10}–10^{11} bacteria /g,[4] 6000–50000 bacterial species/g[5] and up to 200 million fungal hyphae/g.[6] It is well established fact that micro-flora and micro-fauna residing in soil play a very important function in mineral element cycling; the influence of these on crop productivity and natural diversity is still not fully estimated. These beneficial soil microorganisms occupy the rhizosphere /endorhizosphere zone of plants roots and elicit physico-chemical reactions for the plants through various processes. Microorganisms could participate as an important agent in this respect, if their distinctive properties of tolerance to adverse edaphic factors like high or low pH, salinity/alkalinity, moisture limitations, their universal presence, species/strain level biodiversity, interaction with crop plants are being suitably assessed. It is also very much pertinent to devise tools and techniques for their successful application in crop production systems of different agro-ecological regions. Soil microbes also influence plant's reaction towards limited moisture, low/high temperature, salinity, and heavy metal toxicity, by employing various physiochemical reactions such as stimulation of production of osmo-protectant molecules, plant growth regulators and heat shock proteins in plant cells.[7] Unlike synthetic chemicals, these microbiological measures help plant growth and development process without adversely affecting the environmental sustainability. Hence, utilization of phyto-beneficial microbes in crop production and eco-friendly management of biotic and abiotic stresses is gaining importance due to natural availability and its sustainability.[8–9]

Many agriculturally important crop plants at global level are prone to several abiotic stresses such as high or low temperature, salinity, drought, acidic soils, and heavy metal toxicity. Depending on the type of crop, such abiotic stresses cause yield losses upto 50 - 82 percent.[10] As a consequence of the abiotic stress, plants undertake a variety of metabolic and physiological reactions to fight with these stresses. Synthesis of ethylene, a gaseous plant growth regulator commonly known as fruit ripening hormone is one of the major physiological responses shown by stressed plants. Various abiotic stresses typically excite the synthesis of 1-aminocyclopropane 1-carboxylic acid (ACC), which is a forerunner of ethylene synthesis in plants. Ethylene helps to encourage various physiological changes in the plants including activation of a senescence retort in the plants, leading to leaf or fruit fall, disease development, prevention of enzymes synthesis, and in due course admonition of growth.[11–13] Microbial interactions with plants are basic and essential segment of soil-ecosystem, because phyto-beneficial microbes alter local and systemic physiological responses in plants to provide coping mechanism under adverse plant growth situation for survival of both plants as well as microbes. Plant-microbe niche have complex reactions within the plant cellular system as well as rhizosphere zone. Recent plant molecular level studies in this regard are very much helpful in understanding the integrated cellular processes[14] between plants and microbes during their interaction. Metabolites produced by rhizospheric microbial species are involved in both direct as well as indirect plant growth promotion. It is well known that many of the rhizosphere bacteria show the ability to produce plant growth regulators like cytokinins, gibberelins, etc.[15] A number of microbial metabolites such as auxins, gibberellins and iron chelating siderophore are more studied examples for plant microbe interaction. Recently the auxins (Indole Acetic Acid) produced by *Pseudomonas* sp., *Rhizobium* sp., *Enterobacter* sp., *Pantoea* sp., *Marinobacterium* sp., *Acinetobacter* sp., and *Sinorhizobium* sp., have been reported to impact the germination and seedling growth of wheat under saline conditions.[16] Similarly, the native strains of phosphate solubilizing *Bacillus* sp. increased the yield and essential oil content of fennel seeds under semi-arid saline soil condition.[17]

ACC-deaminase activity

The plant growth regulator, ethylene, is needed by plants for their normal growth, to stop seed dormancy. It is known that excess amount of ethylene hormone after seed germination is inhibitory for root elongation. A number of phyto-beneficial microbial strains are known to produce the enzyme 1-amino-cyclopropane-1-carboxylate (ACC) deaminase enzyme that disintegrate the plant ethylene precursor ACC into ammonia and α-ketobutyrate and inturn lowers the amount of ethylene and the ease in related stress condition of plants.[18,19] ACC deaminase is produced by Phyto-beneficial bacteria to efficiently shield plants against a wide range of abiotic stresses as mentioned in earlier text. Rhizobacteria belonging to the genera *Pseudomonas*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Enterobacter*, and *Kluyvera* have been observed to possess ACC deaminase enzyme.[11,19] Arid and semi-arid region crops experience both atmospheric and edaphic stress that can be ameliorated by application of native phyto-beneficial microbes. Native bacterial strains from arid and semi-arid regions of western India were evaluated to promote growth and yield of coriander under open field conditions. Highest seedling vigour index was recorded for *Bacillus aerophilus* Cor-15 (1178.50) followed by *Bacillus megaterium* (1125.20) and minimum was observed with control. The maximum total chlorophyll content was assayed with *Bacillus subtilis* NRCSS-I which was 1.38 mg/g f wt and 1.30 mg/g f wt at 45 and 90 DAS respectively. The highest Pox activity was recorded with B. megaterium ISB28 (4.31 IU/min/g) in coriander shoot tissues at 90 DAS followed by *B. aerophilus* cor-15. At harvest stage, maximum plant height was recorded with *B. aerophilus* Cor-15(84.36cm) which was at par with *B. megaterium* (82.90 cm). Coriander seed yield ranged from 1128.80 to 1650.94 kg/ha and the maximum seed yield of 1650.94 kg/ha was recorded with *B. aerophilus* Cor-15 being at par with *B. subtilis* strains and the minimum in control. Maximum essential oil yield was recorded with *B. megaterium* ISB-28(5.86 l/ha) followed by *B. aerophilus* Cor-15 (4.64 l/ha) and least was observed with control (3.09 l/ha).[20] Similarly, native rhizobacteria strains from western semi-arid region of India were evaluated for the growth promotion in Isabgol (*Plantago ovata* Forsk.) in which the highest seed yield per plant (0.72 g) was observed with *B. aryabhattai* followed by *Azotobacter vinelandi.i*[21]

Salinity stress is one of the major emerging abiotic causes that prevents plant growth by means of poor seed germination, small seedling growth, reduced vigor and less flowering caused by ionic imbalance, inhibition of mineral and water absorption and this in turn leading to buildup of ethylene hormone in plants. Phyto-beneficial microbes having potential activity of ACC deaminase enzyme lower the amount of ethylene and provide salinity tolerance in the stressed plants.[22] Presence of long term excessive moisture caused by erratic rainfall/irrigation is also one abiotic stress that affects many plants in which generally roots and sometimes whole plant suffers due to lack of oxygen (anoxia). In such a circumstance, synthesis of excessive amount of ethylene results to poor growth inhibition and less yield. Application of ACC deaminase- positive phyto-beneficial microbes could lower down the negative impact of anoxia in such stressed crops.

Plant-water interaction is being disturbed at cellular and plant tissue level due to drought stress which in turn reduce crop production in the largest part of dry regions of the world. Abiotic stress tolerance potential of the native *Rhizobium melilotii* strain isolated from root nodules of fenugreek (*Trigonella foenum-graecum* L.) plant was studied and though the *R. melilotii* preferred lower salt conc. and can grow in pH rage 5-8 but rhizobial inoculation helped the fenugreek plants to grow at higher salinity levels. The seed yield of fenugreek plants increased from 0.54 g plant^{-1} at 300 mM to 1.36 g plant^{-1} at 100 mM salt conc. and below 50 mM there was no significant difference in the yield of fenugreek.[23,24]

Selection and development of microbial inoculants with ACC deaminase- containing rhizobacteria could be one of the strategies to grow cropsin arid and semi-arid regions. With the rising crisis of global warming, heat stress is another menace to world agriculture as particularly high temperature above mean adversely impacts thermal sensitivity of plants and concentration of plant growth regulators in plants which change their developmental and growth. The phyto-beneficial microbe *Burkholderia phytofirmans* having ACC deaminase activity ameliorated heat stress in potato. Similarly, a psycho-tolerant bacterium *Pseudomonas putida* UW4 promoted canola growth at low temperature under salt stress.[11]

In general, microbes having ACC deaminase activity are competent to reduce a number of abiotic stresses faced by plants. The acdS gene coding for the enzyme ACC deaminase can be a very useful screening techniques for the isolation and development of a microbial inoculants that can be used in the management of abiotic stress in plants.[25] Further, there are several reports that the presence of acdS gene and the associated ACC deaminase activity by phyto-beneficial microbes helps successful establishment in the root zone soil of treated plants (Table 1).[26]

Other mechanisms of stress tolerance by phyto-beneficial microbes

Some phyto-beneficial microbes release polysaccharides also known as polysaccharides (EPS) which provide a protective cover to the bacteria from water deficit condition, and simultaneously play an important role in the creation and stabilization of soil aggregates, control of plant nutrients bioavailability, and water absorption through plant roots by formation of biofilms.[7] In general, inconsistencies in the ion flux inside plants result due to salinity stress, but use of exopolysaccharides secreting phyto-beneficial microbes leads to decreased sodium and increased potassium ion concentration and thus reduce salt stress by decreasing the level of sodium ion bioavailable for crop plants.[10,34] Some rhizospheric microorganisms release osmolytes which help plants to increase their osmotic potential within the cell thereby relieving the salt stress through osmoregulation.[35] Abiotic stress in plants consequential from water deficiency and drought could result in formation of reactive oxygen species (ROS) as result of misdirection of electrons during light reaction of photosynthetic process. A significant enhancement in the antioxidant enzymes activities viz; superoxide dismutase, peroxidase and catalase were recorded in stressed plants inoculated with nitrogen fixing bacteria *Azospirillum* and *Azotobacter*.[36]

Table 1 Phyto-beneficial microbial inoculants for some horticultural crops under abiotic stresses

Crop	Type of abiotic stress	Microorganism	Mechanism
Tomato	Salt, drought	*Achromobacter piechaudii*	Synthesis of ACC-deaminase[27]
Grapevine	Low temperature	*Burkholderia phytofirmans* PsJN	Synthesis of ACC-deaminase[28]
Dragonblood (*Pterocarpus officinalis*)	Flooding	AM fungi & *Bradyrhizobium*	Development of adv. roots, aerenchyma and hyper trophied lenticels[29]
Tomato	Ni & Cd Toxicity	*Methylobacterium oryzae, Burkholderia* sp.	Reduced uptake and translocation[30]
Common bean	Drought	*P. polymyxa and Rhizobium tropici*	Change in hormone balance and stomatal conductance[31]
Pea	Drought	*Pseudomonas* sp.	Decreased ethylene production[32]
Lettuce	Drought	*Pseudomonas mendocina* and *Glomus intraradices*	Improved antioxidant status[33]

Increase in production of amino acid proline has been observed in plants treated with phyto-beneficial microbes. The proline plays a role of reactive oxygen scavenger as well as osmolyte that can regulate water balance and improve plant growth under stress. Proline accumulates in different legumes such as *Glycine max* and *Phaseolus vulgaris* as a characteristic response to prolonged severe water stress, and it was shown that there is a direct correlation between proline accumulation and drought tolerance.[37,12] Exogenous application of proline may act as signaling molecule for triggering indigenous production of this stress related amino acid in crop plants such as induction of in vitro flowering in *Vigna aconitifolia* by exogenous application of proline[38] and enhanced growth and seed yield in coriander.[39] Co-inoculation of *Rhizobium* and *Pseudomonas* in *Zea mays* due to resulted into higher proline production in which imparted salt tolerance due to maintenance of relative water content and selective uptake of K^+ ions.[40] Inoculating PGPR capable of producing growth promoting phytohormones IAA and gibberellins could result in increased root proliferation under soil thereby high potential of nutrient absorption by the crop plants.[41]

Trichoderma spp. produce auxins which increase plant growth by alleviating harmful extents of abiotic conditions.[42] Two secondary metabolites, harzianolide and 6-pentyl-a-pyrone from *Trichoderma* were reported to exhibit auxin-like effects in etiolated pea stem[43] and promote the growth. Variations induced by changing environmental conditions in plant metabolism also influence pattern and nature of secreted molecules thereby affecting the level of root colonization by rhizobacteria.[44] Microbe's signaling mechanisms in the rhizosphere are also affected in a similar manner but this is yet to be studied at metabolomic and proteomic level.

Conclusion

To regain sustainability in present chemical fertilizers based agriculture system, we need to further explore the microbial diversity, using modern biotechnological tools helpful in isolation and screening of novel plant growth-promoting microbes. Horticultural crops like fruits, vegetables and spices provide a round the year source of nutrition's besides the major staple food such as cereals and pulses. Application of phyto-beneficial microbes in orchards/ fields will be very much helpful in early establishment under various abiotic stresses prevalent due to global warming and climate change. One of the major challenges faced during successful commercialization of abiotic stress tolerance providing microbes is the irregularity in the effect of microbial inoculation on crops under field conditions. However, consortium of two or more phyto-beneficial microbes having different modes of plant growth promotion could be more beneficial than a single strain of microbial inoculant. The isolation and selection of strains that have more than one phyto-beneficial characteristic such as production of antibiotics, siderophores, indole-3-acetic acid, ACC-deaminase activity may be very effective in ameliorating the abiotic stress tolerance in horticultural crops.

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Conflicts of interest

The authors declare that there was no conflict of interest.

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