

Editorial

# Application of Plant Growth Promoting Microorganism and Plant Growth Regulators in Agricultural Production and Research

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Plant growth-promoting microorganisms (PGPM) are rhizosphere microorganisms that colonize the root environment. Some of them are beneficial rhizobacteria while others are fungi that efficiently colonize roots and rhizosphere [1,2]. These microorganisms are capable of improving agriculture production and can also be used as biofertilizers under stressful environmental conditions. Continuous yield losses due to abiotic stresses are one of the important reasons for socio economic imbalance. As abiotic stresses decrease the synthesis of photosynthetic pigments, plant biomass and yield and negatively impact physiological and biochemical mechanisms, and eventually reduce plant growth and yield. The yield damages due to abiotic stresses vary from 50–82% [3]. The modern cultivation methods play an important role for good agricultural and horticultural practices. These methods include the use of cover crops, living mulches, PGPM, plant growth regulators (PGR) and other biostimulants that can protect the soil degradation and phytopathogens and improve the tolerance of plants to stress [4]. One of the utmost common stress tolerance plans in plants is the overproduction of diverse types of low molecular weight and non-toxic compatible organic solutes. They protect plants from unfavourable environmental conditions by different means like, adjustment of osmotic stress, detoxifying reactive oxygen species, membrane stabilization and protecting the structure of enzymes and proteins [5].

It has been suggested that tolerance mechanisms, such as leaf hydration, increased intrinsic water use efficiency, reduced oxidative damage or improved nutritional status, can explain the contribution of PGPR to the stress resistance of host plants. The use of PGPR and other symbiotic microorganisms, may play an important role in developing strategies to assist water conservation in plants. More precisely, the soil-borne *Pseudomonads* and *Paecilomyces variotii* have received a particular attention because of their metabolic flexibility, excellent root-colonising ability and competence to produce a wide range of enzymes and metabolites that benefit the plant in water conservation and enable them to endure diverse biotic and abiotic stresses [3,6].

Rhizosphere microorganisms as well as plant secondary metabolites are well-known for their role in improving growth patterns of roots as they result in rhizosheaths formation around the roots and protecting them from desiccation, pollutant degradation, maintenance of primary cellular functions and from antimicrobial activity of various predators. Many mechanisms have been described for the action of PGPR [7]. Some strains produce metabolites such as hydrogen cyanide, 2,4-diacetylphloroglucinol; antibiotics, and volatile compounds that motivate plant growth. Other strains are responsible for siderophores production and thus play a critical role in sequestering iron for plants, delay senescence, improve biological control, and produce phytohormones which influence plant physiological processes. Some inoculants enter inside root and establish endophytic populations with compliance to the niche and paybacks to the host plants while some enhance surface area of root, thus attract nutrients uptake, and in turn, tempt plant productivity [8,9]. The application of PGPR alone or in combination with chitosan play an important role in combating salinity stress by maintaining higher chlorophyll content, chlorophyll fluores-



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cence, and antioxidant enzymes activity [10]. Noshin et al. [11] isolated the halo-tolerant bacterial species and evaluated their ability to improve seed germination, plant growth, and phytohormones content in plants grown under saline stress conditions. Similarly, Ahmad et al. [12] noted the synergistic effects of PGPR and biochar on the growth and yield of maize grown under semi-arid climate. The beneficial effects of the fungal strains *aggressivum* f. *europaeum* Tae52481 and *T. saturnisporum* Ca1606 were also evident on the growth and yield of pepper and tomatoes [13].

One of the major benefits of PGPR is to produce effective antibacterial compounds that can be used against certain plant pathogens and pests. Moreover, PGPR arbitrates biological control not directly by eliciting induced systemic resistance against a large number of plant diseases [14]. Allelopathic rhizosphere bacteria also improve the wheat growth as they act as biocontrol agents to control the weeds in wheat growing areas [15]. Whereas, He et al. [16] reported the nematicidal activities of *A. japonicas* against root knot nematodes. These microorganisms are also an essential part of the soil phosphorus (P) cycle as they are concerned in a series of processes that have an effect on the transformation of soil P. Particularly, soil microorganisms are efficient in the release of P from inorganic and organic pools of total soil P by the process of mineralization and solubilisation. Shortage and fixation of P in alkaline calcareous soils initiate a decrease in crop production. The impact of rock phosphate and chemical fertilizers were evaluated in a two year field experiment both individually and in combination with PGPR on the growth and yield of wheat and on physico-chemical properties of soil. The study revealed substantial increases in wheat growth and yield treated with *Pseudomonas* sp. + poultry litter. Whereas, all other treatments i.e., rock phosphate + poultry litter + *Proteus* sp.; rock phosphate and poultry litter; half dose inorganic P from Single Super Phosphate-SSP with 18% P<sub>2</sub>O<sub>5</sub> and poultry litter alone were useful for maintaining the soil biological and biochemical properties [17]. It was also reported that mechanical pot seedling transplanting together with deep nitrogen (N) fertilization significantly improves the yield and antioxidant enzymes activities in rice thus may also play an important role in improving the stress tolerance in test plants [18].

PGPR also assists in phytoremediation and microbial based phytoremediation is one of the utmost developing and environmentally friendly methods used for the purification of pollutants from the soil. The PGPR *S. aureus* K1 revealed to regulate the plant growth and antioxidant enzyme activities by decreasing oxidative stress and chromium (Cr) toxicity by converting Cr<sup>6+</sup> to Cr<sup>3+</sup> and the accumulation of Cr<sup>6+</sup> was significantly reduced in wheat plants inoculated with *S. aureus* K1. This shows that the application of *S. aureus* K1 could be an effective approach to lessen the Cr toxicity in wheat and other crop plants [19]. Various free-living rhizosphere bacteria that promote the growth of plants can be applied in heavy metal polluted soils to alleviate lethal effects of heavy-metals on the flora. These beneficial microbes either entirely inhibit metal ions by inhabiting different metabolic activities or enhance the plant tolerance mechanism to high concentration of heavy metals [20].

Plant growth regulators (PGR) are chemical compounds that play a significant role in plant growth and yield. They are involved in plant's intercellular communication and particularly present in the actively growing tissues of plants [21]. PGR associated with the control of cell division, root formation, embryogenesis, fruit development and ripening, and tolerance to biotic and abiotic stresses [22]. Plant growth regulators are designated in the literature as taking a significant part in acquiring crop management of modern agriculture in conditions of abiotic and biotic stressors. Plant growth regulators may improve the antioxidant activity in plants. Foliar application of GA<sub>3</sub> significantly improved both root length and diameter, root and foliage fresh weights/plant, and root and foliage yields/ha increased with the incremental level of nitrogen and/or GA<sub>3</sub> concentration [23]. Oxalic acid (OA) is an important calcium regulator and plays an important role in fruit yield and quality. In this special issue Benítez García, et al. [24] studied the PGR present in the seaweeds and evaluated their plant growth promoting abilities. Whereas, García-Pastor et al. [25] pointed out the effects of preharvest oxaloacetic acid (OA) treatments on pomegranate trees. They reported an increase in the respiration rate, fruit size, fruit quality and crop yield. The OA

treatment was also augmented to sugars and organic acids content, as well as to bioactive compounds and antioxidant activity. They authors also noted a stimulation in the fruit ripening process, increase in the number of fruits with improved quality. Nawaz et al. [26] studied the effects of seed priming with SA on the growth, pigmentation and mineral concentrations of maize (*Zea mays* L.) grown under B toxicity. The findings suggested that the exogenously applied SA moderates the reaction of plants grown under the boron toxicity, and therefore could be used as a plant growth regulator to motivate plant growth and augment mineral nutrient uptake under B-stressed conditions. Ali et al. [27] studied the effects of  $\alpha$ -Tocopherol foliar spray on the growth, photosynthetic pigments, nutrient uptake, and drought tolerance in maize. They reported that  $\alpha$ -Tocopherol is important in improving water stress tolerance in maize, and its foliar application was found to be effective in decreasing the adverse effects of water-stress on growth by modulating the metabolic activities of plants.

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