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Bacillus spp.: Promising Agents for Plant Growth Promotion

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Abstract

The genus *Bacillus* represent a diverse group of Gram positive, rod-shaped, spore-forming, aerobic bacteria with many species play significant role in plant growth and enhancing plant's tolerance to biotic and abiotic stresses. Owing to functional versatility, widespread distribution and ability to form heat-resistant endospores, *Bacillus* spp. has gained much attention and emerged as potential candidates for microbial inoculants and biostimulants. They colonize both in plant tissues and rhizosphere and closely communicate with the host plant across diverse environments. Beneficial *Bacillus* species improve growth and yield of crop plants by employing several direct and indirect mechanisms. The endospore-forming ability enhances their persistence under adverse conditions and facilitates the development of formulations with prolonged shelf life. Multifunctional potential of plant associated *Bacillus* spp. offers considerable opportunities to improve crop productivity, enhance stress resilience and reduce dependence on chemical inputs, thereby contributing to sustainable crop production.

Keywords: *Bacillus* spp., Biological control, Endophytic bacteria, Rhizosphere bacteria

Introduction

Plants are frequently exposed to various biotic and abiotic stresses in their natural habitats. These adverse conditions cause yield reductions in major crop plants throughout the world. Different cultivation practices have been adopted by farmers to reduce the impact of stressors on crop plants. Conventionally, biotic and abiotic stresses caused by various factors have been managed by practicing crop rotation, cultivating resistant varieties and application of chemical inputs. Most of these strategies were found to be less effective with severe impact on the environment and crop production. The need for sustainable crop production demands promising alternatives to hazardous agrochemicals and conventional strategies. Many bacteria have the ability to improve plant health and yield, even under biotic and abiotic stresses, that can be explored as environment friendly alternatives to conventional strategies.

Plants are associated with diverse microorganisms including bacteria, archaea, fungi and algae residing on or inside plant tissues. These microbial communities comprise numerous beneficial members that closely interact with plants and strengthen the plant's defense system against biotic and abiotic stressors. Numerous reports on beneficial bacteria enhancing plant growth and controlling devastating pathogens are available in the literature and undoubtedly, many more promising candidates, yet to be exposed, occur in our environment. Among them, *Bacillus*, a spore-forming, Gram-positive, rod-shaped bacteria, is widely recognized as an efficient plant growth promoting bacteria (PGPB) because of its multiple plant growth-promoting traits, including nutrient mobilization, phytohormone synthesize, suppression of phytopathogens and enhancement of plant tolerance to abiotic stresses. Moreover, the members of this genus are widely known as microbial factories since they supply an array of biologically active molecules, comprising potential antifungal agents (Salazar *et al*., 2023). *Bacillus* spp. is the most predominant bacterial genera in the soil and rhizosphere, covering 95% of the Gram-positive

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soil bacteria and one of the most prevalent endophytic bacteria reported to date. Their physiological ability to form endospores makes them highly resistant to stress or adverse environmental conditions and thrive in a wide range of habitats. The beneficial role of *Bacillus* spp. on different crops such as amaranthus, chilli, black pepper, soyabean, wheat, maize, chickpea, sugar beet, cotton *etc.*, have already been demonstrated by several researchers. We observed a significant increase in growth and biomass of tomato seedlings when seeds were bacterized with a plant growth promoting *Bacillus* strain (Figure 1).



Figure 1: Effect of seed bacterization with plant growth promoting *Bacillus* on tomato seedlings

Recent investigations suggest that *Bacillus* based bioformulations have more advantages over other bioinoculants due to its prolonged shelf life, which is comparable with that of chemical pesticides.

Plant Growth Promoting Ability of *Bacillus*

Many members of genus *Bacillus* are reported to enhance crop productivity by employing direct or indirect mechanisms (Miljaković *et al*., 2020) (Figure 2). Direct mechanisms include, increasing the availability of nutrients and trace elements such as nitrogen, phosphorus, potassium and iron, present in the soil in an unavailable form for plants. *B. subtilis*, one of the most studied *Bacillus* species, is an efficient atmospheric nitrogen fixer and is also known to improve the nodulation in legume plants. Several *Bacillus* species are potent enough to solubilize soil phosphorus by releasing organic acids that helps in converting insoluble phosphorous into soluble form. In addition, iron, an essential plant nutrient, is often a limiting factor for plant development. Under iron limiting conditions, beneficial *Bacillus* species can either upregulate the plant genes involved in iron uptake or acidifies rhizosphere for better iron mobility.

Besides nutrient mobilization, phytohormone production is yet another important direct mechanism that has profound influence on plant development. The *Bacillus* species can regulate the levels of phytohormone like cytokinins, gibberellins, auxins, abscisic acid and ethylene, in plants under different environmental conditions. These compound play key roles in many developmental processes such as cell division and elongation, tissue differentiation, seedling vigor, flowering, fruiting and root development.

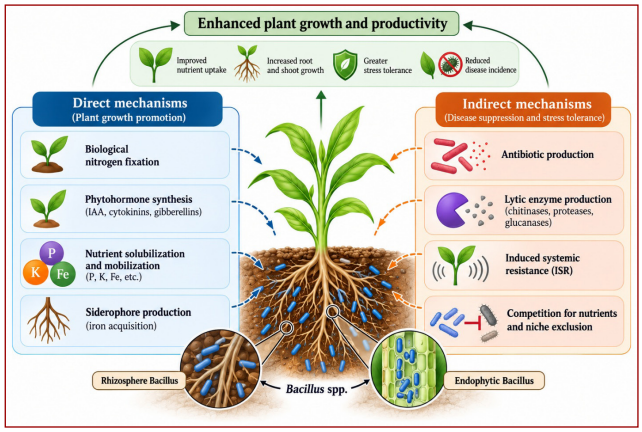


Figure 2: Direct and indirect plant growth-promoting mechanisms of *Bacillus* spp.

Indirect growth promoting strategies of *Bacillus* species support the plants mainly during abiotic stress where it prevents or suppress deleterious phytopathogens by competing for nutrients and space, producing wide range of antimicrobial compounds (antibiotics, hydrogen cyanide and siderophores), inducing systemic resistance in plants and producing a number of lytic enzymes (chitinase, proteases and glucanases) (Table 1).

Yet another major challenge in sustainable crop production is the abiotic stress. Global climate change significantly alters the environment and causes several abiotic stresses such as drought, temperature, heat, salinity and heavy metal stress. Of various abiotic stresses, an increase in the mean temperature of the climate is the most challenging stresses experienced by plants. Plant associated microorganisms have a dynamic co-evolutionary relationship where they can sense the need of plants through chemical signals and enable the plant to withstand stress. *Bacillus* can survive high temperature conditions by producing heat-resistant spores, where plants fail to withstand and modify root architecture, regulate water relations, nutrient uptake and phytohormone levels and keep the plant tolerant to drought. Taking into account multiple beneficial traits of the genus *Bacillus*, further research into plant growth promoting ability of *Bacillus* members is essential to develop successful commercial products, particularly when biotic and abiotic stressors challenge our ability to feed growing world population.

Diversity and Isolation of *Bacillus* spp.

The genus *Bacillus* has been reported across diverse environments, comprising members associated with both the rhizosphere and the internal tissues of plants as endophytes. The plant rhizosphere accommodates diverse range of microbes and the bacteria residing this habitat are known as rhizobacteria. Multiple rhizosphere *Bacillus* spp. with varying abundance and functional attributes has been documented as plant growth promoting rhizobacteria (Akinrinlola *et al*., 2018). Many of them were found to be actively involved in biotic activities that make soil healthy

Table 1: Plant growth-promoting activities of *Bacillus* spp. in different crop plants

Bacillus Species	Major function	Host plant
Bacillus licheniformis FMCH001, *Bacillus subtilis* FMCH002	• Indole acetic acid production. • Plant growth enhancement.	Tomato
Bacillus sp. PG-8	• Production of indole acetic acid, gibberellic acid, ammonia and exopolysaccharide. • Phosphate solubilization. • Stimulate plant growth.	Ground nut
Bacillus sp. (K7)	• Production of indole acetic acid, ammonia, siderophores, cellulases, amylases and proteases. • Atmospheric nitrogen fixation. • Biocontrol activity against *Colletotrichum siamense*. • Improve seed germination.	Chilli
Bacillus pumilus VLY17	• Indole acetic acid production. • Suppression of foot rot pathogen. • Promotes growth of black pepper.	Black pepper
Bacillus velezensis JB0319	• Alleviate salt stress. • Promote plant growth. • Increase the activity of reactive oxygen scavengers.	Lettuce
Bacillus subtilis ER-08	• Production of indole acetic acid and gibberellins. • Production of ammonia, hydrogen cyanide, exopolysaccharides, siderophore, cellulase, pectinase, protease and chitinase. • Suppression of *Fusarium oxysporum*.	Fenugreek

and optimal for crop production. In addition, *Bacillus* spp. is known to colonise intracellular and intercellular spaces in many crop plants and closely communicate with host by producing a variety of chemical molecules. These compounds from endophytic *Bacillus* have tremendous impact on plant growth and development.

Nowadays, plant-associated *Bacillus* spp. is widely used as biocontrol and plant growth promoting agents. Many plant-associated beneficial bacteria have been developed as commercial biostimulants. However, *Bacillus* spp. based biostimulants were found to be more efficient than those based on other beneficial bacteria (*e.g.*, *Pseudomonas)* because of the production of wide array of metabolites. Using *Bacillus* strains as inoculants are of great advantageous due to their sporulation property. This character helps in the selective isolation spore-forming *Bacillus* from a complex microbial community present in soil, rhizosphere and plant-associated samples. *Bacillus* spp. can be isolated from diverse environmental samples following conventional isolation protocol. However, two-step enrichment method involving drying and heating of sample was found to be an efficient method that selectively enrich endospore-forming Bacilli and eliminate all vegetative cells (Yashaswini *et al*., 2021). Following enrichment, the recovered bacterial isolates can be cultured on suitable media and identified based on morphological, biochemical and molecular characteristics. These isolates can subsequently be screened for plant growth-promoting traits to identify promising candidates for the development of effective and environmentally sustainable bioinoculants.

Conclusion

The genus *Bacillus* comprises plethora of functionally versatile species widely used in agriculture. Many of them are reported to involve directly or indirectly in plant developmental processes. Their multiple growth promoting mechanisms include phytohormone production, nitrogen fixation, solubilization and mobilization of various nutrients and siderophore production, whereas indirect mechanisms include production of antibiotic metabolites, lytic enzyme and siderophores and induction plant's defense system. Beneficial rhizosphere and endophytic *Bacillus* represent efficient biocontrol agent, biofertilizer and biostimulant in agriculture and their full potential remains to be completely identified. Recent researches suggest that more emphasis should be given on translating laboratory-based knowledge into practical field applications to harness the beneficial attributes and maximize their contributions to sustainable agriculture.

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