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Bacillus - A Potential Bio-Fertilizer for Sustainable Agriculture and Environment

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Abstract

Eco-friendly agriculture is becoming more and more popular; however, the extensive and excessive use of agrochemicals can increase soil contamination, raising threats to the environment and human health. Beneficial microorganisms are becoming more and more popular in organic agriculture as substitutes for synthetic fertilizers and pesticides. Biocontrol approach is ecofriendly technique to maintain the soil fertility using beneficial microbes. Among the beneficial microbes in organic, environmentally friendly agriculture, members of the genus *Bacillus* have a specific place. *Bacillus* spp. is the most prominent plant growth promoting rhizobacteria due to its ability to form long-lived, stress-tolerant spores, which makes them the greatest options for successful and long-lasting bio formulations. Numerous strains of *B. subtilis* and *B. amyloliquefaciens* have reportedly been used extensively as growth promoters and biocontrol agents.

Key Words: Organic farming, *Bacillus*, biofertilizer, organic farming, PGPR, sustainable agriculture

Introduction

Rhizosphere plant microbiota is the term used to describe the diverse array of microorganisms that coexist with plants. Rhizosphere: The area of the soil near the roots where the roots interfere with nourishment (Basu *et al.*, 2021). In addition to performing photosynthesis, plants also invest 10–40% of their photosynthetic metabolites in the rhizosphere through rhizodeposition, depending on the species (Vetterlein *et al.*, 2020). Plant growth-promoting rhizobacteria (PGPR) are a class of soil microorganisms that affect plant roots in a beneficial way through a number of ways. Plant growth promoting rhizobacteria, or PGPR, are beneficial microbe-plant interactions that can greatly increase plant development. Bacillus is an aerobic, rod shaped, endospore forming bacteria, numerous species in the genus *Bacillus*, including *B. subtilis, B. subtilis, B. macerans, B. megaterium, B. coagulans, B. azotofixans*, etc., are acknowledged as powerful PGPRs. There are several ways in which *Bacillus* strains work, some of which include improving the process of sequestering carbon dioxide, acting as a strong denitrifying agent, and mobilising nutrients such as nitrogen, potassium, phosphorus, zinc, indole-3-acetic acid, and gibberellic acid (Mahapatra *et al*., 2022).

Role of Bacillus in Organic Farming

Nitrogen fixation by *Bacillus*

Nitrogen is one of the most important nutrients for plants because it is the main component of chlorophyll and makes up some of the proteins, nucleic acids, and other important biomolecules that plants need to grow normally. An estimate of 175 million metric tonnes, or around 70% of all nitrogen fixed on Earth annually, is fixed biologically in the atmosphere; the remaining portion is fixed by various microorganisms, either autotrophic or heterotrophic "free" fixers (Peter *et al*., 2002). According to Mirza *et al*. (2012), biological nitrogen fixation is one of the most significant natural processes on Earth. It is carried out by diazotrophic bacteria, which replenishes a set amount of nitrogen in the environment. The genes that encode the enzymes needed for fixing atmospheric nitrogen are known as nif genes. The nitrogenase complex, the main enzyme expressed by the nif genes, is responsible for transforming atmospheric nitrogen into different forms of nitrogen that plants may utilise for a variety of functions, such as ammonia. Both free-living nitrogen-fixing bacteria and symbiotic bacteria that are intimately linked to a wide variety of plants include these nif genes. Nif genes are present in a large number of *Bacillus* species, such as *Bacillus aerophilus, B. aquimaris, B. massiliensis, B. cereus, B. firmus, and B. megaterium*.

Phosphorous solubilisation by *Bacillus*

About 0.2% to 0.8% of a plant's dry weight contains phosphorus (P), which is the second most essential macronutrient after nitrogen and is required for basic biological processes as well as plant growth and development. Plants take phosphorus in the form of phosphate anions, but precipitation with cations such as Fe^{3+}, Mg^{2+}, and Ca^{2+} immobilises these phosphate anions in soil, depriving plants of phosphorous. Soil microorganisms known as phosphorus solubilizing microorganisms (PSMs) transform accessible forms of phosphorus into phosphates that are soluble. Different strategies have been developed by *Bacillus* (*Bacillus subtilis, B. cereus, B. thuringiensis, B. pumilus, B. megaterium,* etc.) to increase plant growth by increasing the availability of the nutrient (Meena *et al*., 2016). The solubilization of insoluble inorganic phosphate compounds, like tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate, is achieved through oxidation-reduction reactions, acidification of organic acids, and increased activity of acid phosphatases, which results in the mineralization of organic phosphorous (Sharma *et al*., 2013). These mechanisms are the means by which phosphate is solubilized by phosphate-solubilizing microorganisms.

Potassium solubilization and mobilization by *Bacillus*

Potassium (K) is the most significant plant nutrient, playing an essential role in the growth, metabolism, and development of plants, after nitrogen (N) and phosphorus (P). K is necessary to activate more than 80 different enzymes that are involved in energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar degradation in plants and animals. It also increases plant resistance to abiotic stresses, diseases, and pests (Hussain *et al*., 2016). Even though K is an abundant component in soil, plants can only use 1% to 2% of it. Plants cannot utilise the remaining minerals since they are bonded with other minerals. Rhizosphere bacteria play a major role in the release of potassium from different insoluble potassium components present in soil and surrounding environments. One such bacterium is Bacillus, which has been identified as a potassium-solubilizing and mobilizing bacterium in numerous studies. *Bacillus circulans, B. edaphicus, and B. mucilaginosus* solubilize fixed forms of K in soil and make them accessible to plants by producing organic acid, forming biofilms on mineral surfaces by acidolysis, and forming complexes (Maurya *et al.*, 2016).

Micronutrient mobilization by *Bacillus*

Plant roots may absorb iron in its reduced ferrous state (Fe^{2+}), even while soil contains iron in its oxidised ferric form (Fe^{3+}). Like N, P, and K, iron is a necessary nutrient for plants, but it is also insoluble in soil solutions. The majority of rhizosphere microorganisms bind iron by siderophores, which might raise the concentration of soluble iron in the soil around the roots. In addition to increasing iron intake and removing heavy metals from the environment, these siderophore-producing microorganisms are important for biocontrol action against plant diseases in the rhizosphere. The different Bacillus species that generate siderophores are *B. anthracis, B. atrophaeus, B. thuringiensis, B. cereus, B. velezensis, B. mojavensis, B. pumilus, B. halodenitrificans,* and *B. subtilis* (Goswami *et al*., 2014).

Bacillus as biocontrol agent

In recent years, the interest in biological control of plant pathogens has significantly increased, due to the need for introduction of more environmentally friendly alternatives to the massive use of chemical pesticides (Ongena and Jacques, 2008). Many strains of microorganisms have growth-promoting qualities on plants in addition to their protective effects. The most significant role that *Bacillus* plays in biological control is that of soil and plant-associated bacteria. *Bacillus* species are more effective due to their resistance to adverse environmental conditions and ability to control broad range of pathogens. *Bacillus* species directly antagonize fungal pathogens by competition for nutrients and niches, by producing antifungal and antimicrobial compounds (lipopeptides, antibiotics and enzymes), and indirectly by inducing induced systemic resistance (ISR) or activate the plant immune system or by promoting plant growth with different mechanisms such as siderophore production (Kulkova *et al*., 2023). List of various *Bacillus* strains exploited as biological control for various plant pathogens are tabulated in Table 1.

Conclusion

One of the most common bacterial genera in soil is the genus *Bacillus*, of which numerous species have been identified from a variety of biological settings. It is well known that members of the genus *Bacillus* possess a variety of advantageous characteristics that either directly or indirectly benefit plants. These characteristics include the acquisition of nutrients, the general improvement of growth through the production of phytohormones, phytoremediation, the alleviation of various abiotic stresses, and the biocontrol of various plant diseases and pests. A few of these inherent multi-potential benefits include antibiosis, competition (nutrients), mycoparasitism, and the induction of systemic resistance in host plants. This functionally versatile genus is one of the most commercially exploited bacteria in the agro-biotechnology industry. Bio formulations based on *Bacillus* are a viable alternative to chemical fertilizers and pesticides and could play a significant role in sustainable organic agriculture.

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Table 1. List of *Bacillus* strains exploited as biological control against various plant pathogens in various crops.

S. No	Crop	Disease	Pathogen	Strain	Mode of action	Reference
1	Tomato	Bacterial wilt	*Ralstonia solanacearum*	*B. subtilis, B amyloliquefaciens*	Lipopeptide compounds such as surfactin, fengycin and etc.	Sakthivel *et al*. (2017; 2023)
2	Wheat	Wheat sharp eyespo	*Rhizoctonia cerealis*	*Bacillus subtilis* XZ18-3	DNA fragmentation, accumulation of ROS and changes in cell membrane permeability	Yi *et al*. (2022)
3	Sugar beet	Leaf spot	*Pseudomonas syringae*	*B. pumilus* SS-10.7 and *B. amyloliquefaciens* SS-12.6 and SS-38.4	Crude lipopeptide extracts	Nikolić *et al*. (2019)
5	Tomato	White mold	*Sclerotinia sclerotiorum*	*B. velezensis*		Farzand *et al*. (2019)
6	Citrus	canker	*Xanthomonas citri subsp. citri*	*B. thuringiensis*	Antimicrobial compounds	Islam *et al*. (2019)
7	Potato	Common scab	*Streptomyces scabies*	*B. amyloliquefaciens* Ba01	Secondary metabolites such as surfactin, and fengycin	Lin *et al*. (2018)
8	Cabbage and pepper	Black rot and bacterial leaf spot	*Xanthomonas campestris*	*Bacillus* spp.	-	Pajcin *et al*. (2018)
9	Tomato	Wilt	*Fusarium oxysporum*	*B. velezensis*	Antibiotic biosynthetic genes viz., Iturin A, Iturin C, Surfaction, Bacillomycin A and Bacillomycin D	Elanchezhiyan *et al*. (2018)

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