



Plant Growth-Promoting Rhizobacteria: Mechanisms and Agricultural Applications

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DESCRIPTION

Plant Growth-Promoting Rhizobacteria (PGPR) is a group of beneficial bacteria that colonize the root zone of plants and enhance plant growth and health through various mechanisms [1]. These bacteria are naturally present in the soil and can be isolated from the rhizosphere the region of soil influenced by plant roots. PGPRs are gaining significant attention in agriculture due to their ability to improve crop yield reduce the need for chemical fertilizers and pesticides and promote sustainable farming practices. The diverse mechanisms through which PGPR promote plant growth and the wide array of potential applications in agriculture makes them a valuable tool for enhancing crop production and soil health [2].

One of the primary mechanisms by which PGPR promote plant growth is through the fixation of atmospheric nitrogen [3]. Nitrogen is an essential nutrient for plants and while it is abundant in the atmosphere plants is unable to utilize it in its gaseous form. Certain PGPR species such as those in the genus *Rhizobium* have the ability to fix nitrogen by converting atmospheric nitrogen into a form that plants can absorb such as ammonium. This process is particularly beneficial in nitrogen-poor soils where the addition of nitrogen fertilizers may not be feasible or desirable. By enhancing nitrogen availability PGPR can significantly improve plant growth and productivity without the environmental drawbacks associated with synthetic fertilizers [4]. In addition to nitrogen fixation PGPR can also enhance plant growth through the production of plant hormones. One of the most common plant growth-promoting hormones produced by PGPR is Indole-3-Acetic Acid (IAA) a form of Auxin. Auxins are critical for regulating various aspects of plant growth including cell elongation root development and flower formation [5]. PGPRs that produce IAA can stimulate root development resulting in a more extensive and efficient root system. This enhanced root growth allows plants to absorb water and nutrients more effectively leading to improved overall growth especially under nutrient-limiting conditions or drought stress [6]. PGPR also promote plant growth through the production of

Siderophore which are compounds that bind to iron and make it more available to plants. Iron is an essential nutrient for plants but is often present in the soil in forms that are not easily accessible to plant roots [7]. Siderophore-producing PGPRs help solubilize iron and facilitate its uptake by plants which can lead to improved plant health and growth. This mechanism is particularly important in soils where iron availability is limited such as alkaline or waterlogged soils [8].

Another important mechanism through which PGPRs promote plant growth is by suppressing the growth of harmful soil-borne pathogens. Many PGPR species produce antimicrobial compounds such as antibiotics hydrogen peroxide or volatile organic compounds that can inhibit the growth of pathogenic microorganisms in the rhizosphere [9]. This biological control mechanism helps protect plants from diseases caused by fungi bacteria and nematodes. By outcompeting or antagonizing plant pathogens PGPRs reduce the need for chemical pesticides and contribute to Integrated Pest Management (IPM) strategies that are more environmentally friendly and sustainable. In addition to directly suppressing pathogens PGPRs can also induce systemic resistance in plants. This phenomenon known as Induced Systemic Resistance (ISR) is a defense mechanism where the plant's immune system is activated in response to PGPR colonization. Once activated the plant becomes more resistant to a broad range of pathogens including fungi bacteria and viruses even those that have not directly interacted with the PGPR. This immune priming effect provides long-lasting protection and can help plants cope with future infections [10].

CONCLUSION

PGPRs also improve plant growth under abiotic stress conditions. Plants face various environmental stresses such as drought salinity and extreme temperatures which can significantly hinder their growth and productivity. PGPRs help plants tolerate these stresses by producing compounds that enhance stress resistance. For example some PGPRs produce exopolysaccharides that help retain moisture in the soil reducing

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the impact of drought stress. Others can modulate plant metabolism to help plants cope with salt stress by reducing the accumulation of toxic ions in plant tissues. The ability of PGPRs to alleviate abiotic stress makes them valuable tools for improving crop productivity in challenging environmental conditions.

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