



PGPR as Sustainable Alternatives to Chemical Pesticides in Agriculture

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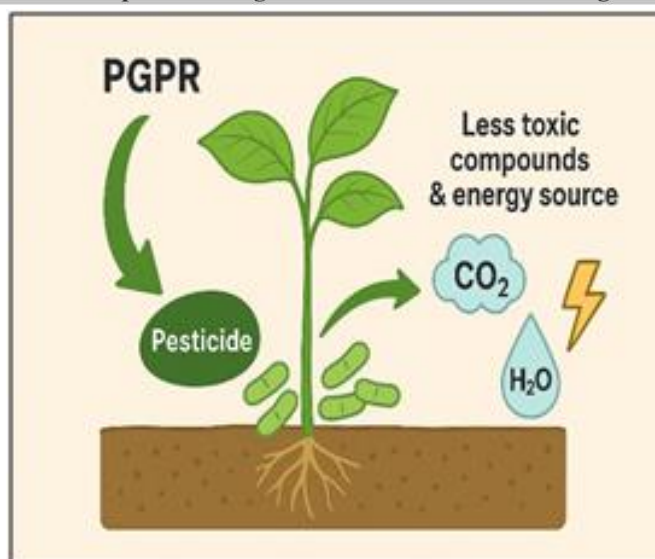
INTRODUCTION

Look beyond Pesticides

Pesticides have been recognized as the "miracle weapon" of agriculture for many years. Pesticides are formulated chemicals which used to eradicate or manage pests in field and storages, such as rodents and insects. They helps farmers obtain higher yields and safeguard food supply by controlling weeds, pests, and illnesses. But there are consequences to this extensive use of chemical pesticides, including soil deterioration, contamination of the environment, health hazards, and the emergence of insect resistance. Bioaccumulation that affects both humans and animals in the food chain, pest resistance, necessitating the use of more potent pesticides. Scientists are actively looking for natural alternatives in the modern world, where sustainability and environmentally friendly solutions are more crucial than ever. Plant Growth-Promoting Rhizobacteria (PGPR) has become a soil and crop savior among them. They live naturally in plant roots and able to reduce pesticide pollution present in soil, in addition to enhancing plant development, these beneficial microorganisms serve as organic defense against dangerous pests and illnesses. More significantly, some PGPR may break down chemical pesticides in the soil, which has the dual benefits of lowering pesticide pollution and organically safeguarding crops.

PGPR: Beneficial Microbial Allies

Plant growth promoting rhizobacteria (PGPR) is group of bacteria that are found in the rhizosphere of plants that enhance plant growth, development and protection. PGPR penetrate plant roots and promote development in a number of ways. *Pseudomonas*, *Bacillus*, *Rhizobium*, *Azospirillum*, *Enterobacter*, and *Burkholderia* are among the genera to which they belong. PGPR's Functions in Agriculture: Mobilization of Nutrients: Fix nitrogen, solubilize phosphorus, and release micronutrients for plant uptake. Auxins, gibberellins, and cytokinins are produced as phytohormones to promote plant growth.



Biocontrol Activity like siderophores, antibiotics, or competition to suppress dangerous diseases. Plant protection against pathogens is strengthened by Induced Systemic Resistance (ISR). PGPR are important for improving plant survival and productivity in challenging and unfavourable environmental conditions like drought, salinity, and heavy metal pollution. Certain PGPR strains have developed the ability to degrade harmful pesticide which are present in soil, and transforming them into less toxic or harmless substance.

PGPR assistance in Pesticide Degradation

PGPR another function in the biodegradation of pesticides available in soil is among most remarkable abilities of these microbes. Enzymes that can convert pesticides as a source of energy or nutrients have developed in certain bacteria. PGPR break down pesticides using intricate ecological and biochemical processes that change toxic pesticide residues into less hazardous or non-toxic substances. The production of a several of enzymes by PGPR, including hydrolases, oxygenases, dehalogenases, and esterases, that selectively target and degrade pesticide compounds, is one of the main techniques. Organophosphorus hydrolases and esterases, for example, hydrolyse organophosphates like parathion and chlorpyrifos to produce simpler, less hazardous byproducts like phosphate ions and p-nitrophenol. In the same manner, Dehalogenases break down lindane and DDT, among other organochlorines, by removing chlorine atoms from the compound, a key step in detoxification.

Some PGPR might also use pesticides directly as a source of nutrients through a process

called metabolic degradation, it uptake carbon, nitrogen or phosphorous inside the cell and its breakdown product into their own metabolism which leads into production of harmless end product, and this minerals are used as an essential energy source. For example, *Pseudomonas putida* has been shown to use enzymatic activity involving oxygenases and hydrolases to break down pesticides like atrazine and parathion, *P.putida* strain PC1, which was isolated from the agricultural soil, metabolises and completely degrade the organophosphate pesticide. PGPR and other microbes, including *Pseudomonas aeruginosa* and *Aspergillus terreus*, have shown that they can effectively degrade chlorpyrifos through the production of laccase and synergistic enzymatic activity.

Mechanisms of PGPR-Mediated Pesticide Degradation

Enzymatic Decomposition

Enzymes that target pesticide compounds, including phosphatases, hydrolases, esterases, dehalogenases, and oxidoreductases, are produced by PGPR. For instance, *Pseudomonas* species can use parathion hydrolase to break down organophosphates like parathion.

Cometabolism

Pesticides can occasionally be broken down by bacteria as a consequence of eating other carbon sources rather than as their main food source. Pesticides are completely broken down into simple, non-toxic substances like CO₂, H₂O, and inorganic ions. This process change harmful pesticides undergo partial degradation, transforming into less harmful intermediates.

Table 1. Microbial Degradation of Different Classes of Pesticides

Pesticide Class with Examples	Microbial Species and Degradation Mechanism
Organophosphates (e.g., Malathion, Parathion, Chlorpyrifos)	<i>Pseudomonas putida</i> and <i>Flavobacterium</i> sp. produce organophosphorus hydrolases the compounds.
Carbamates (e.g., Carbofuran)	<i>Burkholderia cepacia</i> degrade carbofuran into less toxic compounds.
Organochlorines (e.g., Lindane, DDT)	<i>Bacillus</i> and <i>Sphingomonas</i> species help in transformation and slow mineralization.
Triazines (e.g., Atrazine)	<i>Pseudomonas</i> and <i>Agrobacterium</i> species degrade atrazine through hydrolytic enzymes.

Benefits of PGPR in Reducing Pesticide Dependence

Plant Growth-Promoting Rhizobacteria (PGPR) offer multiple benefits that make them a sustainable alternative to chemical pesticides. By naturally breaking down harmful chemicals, they help reduce pesticide residues in soil and water, keeping the environment cleaner and safer. Their presence also improves soil health by supporting beneficial microbes and maintaining the natural balance of the ecosystem. Acting as natural biocontrol agents, PGPR protect crops from diseases and pests in a sustainable way, reducing the need for repeated chemical sprays. This not only lowers farming costs but also ensures healthier harvests with minimal pesticide residues, ultimately contributing to safer food for consumers and a healthier planet for future generations.

CONCLUSION

Pesticides though good for plant protection and yield enhancement, but its long term use may effect in whole environment directly and indirectly. This causes destruction of soil, plant animals and human health. The integration of PGPR in farming is a promising step toward sustainable agriculture. Advances in biotechnology by augmentation of PGPR strains for faster pesticide degradation are important. It includes Formulation of bio fertilizers and bio pesticides using mixed cultures of PGPR as well as Combining PGPR with organic farming practices for holistic crop protection. Though, field-level application still faces challenges like variable soil conditions, competition with native microbes, and survival under harsh environments. The Continuous research goals to make PGPR-based solutions more reliable and widely adoptable.

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