

PGPR as Dual Action Bioagents: Enhancing Plant Growth and Degrading Plastics

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ABSTRACT

Plastic pollution has become a major global environmental threat due to the persistent nature of plastics like polyethylene, polypropylene, and PET, which resist natural degradation and accumulate in soil, water, and living organisms. Improper disposal results in microplastic formation, disrupting ecosystems and endangering human health. An emerging eco-friendly solution involves the use of plant growth-promoting rhizobacteria (PGPR) and other microbes capable of biodegrading plastics. These microorganisms produce enzymes such as PETase, laccase, and cutinase that break complex polymer chains into simpler, non-toxic compounds like carbon dioxide, water, and biomass. Notably, species such as *Pseudomonas*, *Bacillus*, and *Aspergillus* not only degrade plastics but also enhance soil fertility and plant growth by producing growth-promoting substances. In this article we understand the dual action of microbes which supports both waste reduction and environmental restoration. Even though microbial degradation is often slow and may yield intermediate products, advancements in enzyme and genetic engineering, microbial consortia, and bioreactor technologies are improving its efficiency.

INTRODUCTION

Plastic has become one of the most pressing environmental pollutants of our era. From polyethylene shopping bags to polypropylene bottles, plastic residues are everywhere soil, water, even the food chain (Tareen *et al.*, 2022). They are **synthetic or semi-synthetic polymeric materials** derived mainly from petroleum and natural gas. Their name comes from the Greek word *plastikos*, meaning *capable of being shaped*, reflecting their moldability. Plastics can be formed into films, sheets, fibers, or rigid items, making them versatile and widely adopted in modern society. Plastic has become an essential part of modern life due to its durability, low cost, and wide applications in packaging, household items, medical equipment, and industries. Physically plastic is a polymers that can be molded into various shapes when soft and retain their form once cooled or hardened. They are lightweight, durable, resistant to water, and can be flexible or rigid depending on the type. And chemically it can be defined as long-chain polymers made of repeating units (monomers) derived mainly from petroleum and natural gas. Common monomers include ethylene, propylene, styrene, vinyl chloride, terephthalate, etc.

Plastics may contain additives such as stabilizers, plasticizers, and colorants to modify their properties. Their strong C–C and C–H bonds make them resistant to natural degradation. However, its excessive use and improper disposal have created a serious problem of plastic pollution (Jayasekara *et al.*, 2023). Since most plastics are non-biodegradable, they persist in the environment for hundreds of years, accumulating in landfills, rivers, and lands (Zhao *et al.*, 2025). This leads to harmful effects on wildlife, as animals often mistake plastic for food, and it also releases toxic chemicals during degradation that contaminate soil and water.

The growing plastic waste not only threatens ecosystems and biodiversity but also poses risks to human health, making plastic pollution one of the most pressing environmental challenges today.

Plastic Pollution

Plastic pollution has emerged as a global environmental crisis due to the widespread use and poor management of plastic waste (Dhaka *et al.*, 2023). Plastics are highly durable and resistant to normal degradation, which means they can persist in the environment for hundreds of years. When discarded improperly, they accumulate in landfills, clog drainage systems, and enter rivers and oceans, where they disrupt aquatic as well as agriculture ecosystems. Plastic breaks down into microplastics and nanoplastics, which enter the food chain and now it been detected in soil, water, and even the human body (Tareen *et al.*, 2022), raising concerns about long-term health impacts. The problem of plastic pollution is not just ecological but also economic and social. Clean-up operations require significant resources, and additionally, the burning of plastic waste releases harmful gases, contributing to air pollution and climate change (Jayasekara *et al.*, 2023).

PGPRs Plastic degrading bacteria

Certain microorganisms have the ability to degrade plastics through enzymatic activity, converting them into simpler, non-toxic compounds (Ting & Sallahudin, 2025). This process is called biodegradation. Plastic biodegradation by microorganisms is an eco-friendly solution to combat plastic pollution. Certain bacteria possess specialized enzymes that can break down complex polymer chains in plastics into simpler, harmless compounds. Some plant growth promoting rhizobacteria (PGPR) are used as bacteria plastic

biodegradation bacteria's. They are specifically known for boosting plant growth by enhancing nutrient availability, producing growth hormones, and protecting plants against stress. But current studies reveal their potential for another role plastic biodegradation (Dhaka *et al.*, 2023; Zhao *et al.*, 2025). By breaking down polymers into simpler compounds, PGPR could reduce plastic accumulation while simultaneously improving soil fertility. For example, microbes such as *Pseudomonas*, *Bacillus*, and *Aspergillus* species have been reported to degrade polyethylene, polystyrene, and PET (Ting & Sallahudin, 2025).

The process involves microbial colonization of the plastic surface, secretion of enzymes like hydrolases or oxidases, and subsequent conversion of plastic molecules into smaller units such as carbon dioxide, water, or biomass. Although natural degradation is often slow process, ongoing research is exploring ways to enhance microbial activity through genetic engineering and microbial consortia. This biological approach offers a sustainable and cost-effective alternative to conventional disposal methods like landfilling and incineration, providing hope for reducing long-lasting plastic waste in the environment.

Mechanism of Microbes

Most commodity plastics like as Polyethylene (PE), Polypropylene (PP), Polyethylene terephthalate (PET), PVC (Polyvinyl chloride), and PU (Polyurethane) resist decay because of strong C–C or ester bonds and hydrophobic surfaces (Jayasekara *et al.*, 2023). Microbes mount by different strategies:

- 1. **Surface attack** (often slow): enzymes and reactive oxygen species introduce oxygen into the polymer surface, increasing roughness and wettability.
- 2. **Depolymerization & assimilation:** hydrolases or oxidases cut chains into

shorter fragments/monomers; cells then funnel products into metabolism.

- 3. **Enzyme Secretion:** They secrete enzymes like laccases, cutinases, lipases, and esterases that break down polymer chains.
- 4. **Mineralization:** Finally, plastics are converted into CO₂, H₂O, CH₄, and biomass.

Sl. No	Plastic types	Main Enzymes	Plastic Degrading PGPR
1.	PET (Polyethylene terephthalate)	PETase, MHETase, Cutinase	<i>Ideonella sakaiensis</i>
2.	PE (Polyethylene)	Laccase, Peroxidase, Alkane hydroxylase	<i>Pseudomonas</i> , <i>Rhodococcus</i>
3.	PP (Polypropylene)	Hydrolase, Oxidoreductase	<i>Bacillus cereus</i> , <i>Aspergillus niger</i>
4.	PU (Polyurethane)	Polyurethane esterase, Urethanase, Lipase	<i>Comamonas acidovorans</i>
5.	PS (Polystyrene)	Styrene monooxygenase, Styrene oxide isomerase	<i>Pseudomonas putida</i>
6.	PVC (Polyvinyl chloride)	Dehalogenase, Peroxidase, Laccase	<i>Bacillus flexus</i>
7.	PLA (Polylactic Acid)	PLA depolymerase, Proteinase K	<i>Amycolatopsis sp.</i>

Table No. 1 Important plastic degrading enzymes and secreting PGPRs (source Wei *et al.*, 2025; Ting & Sallahudin, 2025)

The latest studies appearance

- 1. **Rhizobacterial PET degraders:** Rhizosphere isolates (including *Priestia aryabhattai*, *Bacillus pseudomycoides*, *Bacillus pumilus*) reduced PET sheet/powder mass and produced identifiable breakdown products within 18–28 days in minimal media (Dhaka *et al.*, 2023).
- 2. **Engineered PET-active PGPR chassis:** *Pseudomonas putida* strains with genomically integrated PET-hydrolase cassettes can cleave PET and metabolize monomers; performance varies with expression system, secretion tags, and test conditions (Wei *et al.*, 2025).

3. PE degraders from soil/dumpsites:

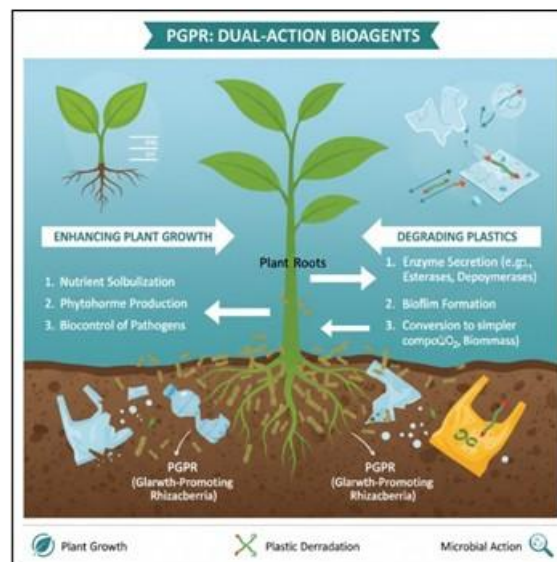
Bacillus subtilis and *B. licheniformis* lowered LDPE film mass by ~2.8–3.5% in 30 days; mixed *Bacillus*–*Priestia* consortia accelerated LDPE changes over 48 days. A recent report implicates *Bacillus paramycoides* in LDPE decay in sedimentary systems (Ting & Sallahudin, 2025).

4. Microplastics + Heavy metals: PGPR

help plants tolerate combined pollution, with metagenomics pointing to stress-alleviation pathways and community shifts important because real soils usually contain **multiple** stressors (Zhao *et al.*, 2025).

“Dual action PGPR” assistances plant and soil

“Dual action” PGPR play a vital role in supporting both plant growth and soil restoration, even in environments polluted with microplastics. These beneficial microbes continue to promote plant development by producing growth hormones like **auxins**, iron-chelating **siderophores**, and **ACC-deaminase**, which help roots grow and function effectively even with the altered soil porosity and water balance caused by plastic pollution Zhao *et al.*, 2025). At the same time, these microbes contribute to the **biodegradation of plastics**, gradually reducing stress on plants as the plastic particles break down and lose their toxic or obstructive effects. Furthermore, some microbial processes enable **carbon recovery** for instance, during the breakdown of PET plastics, the released by-products such as **terephthalic acid (TPA)** and **ethylene glycol (EG)** can be further utilized by engineered microbial strains to produce valuable biochemical (Wei *et al.*, 2025; Jayasekara *et al.*, 2023). This dual role of PGPR not only enhances plant resilience in polluted soils but also supports a **circular bioeconomy** by transforming waste into useful resources.



Limitations and responsible use

While PGPR and other plastic-degrading microbes offer such potential, their use comes with some important limitations and errands. The degradation of plastics like polyethylene (PE) and polypropylene (PP) is inherently slow often taking weeks or even months to accomplish only partial breakdown so the statements of complete biodegradation of plastics in natural environments should be made cautiously (Tareen *et al.*, 2022). Moreover, the degradation process can produce intermediates or micro fragments, as partial oxidation leads to smaller particles or soluble compounds that may still stance of ecological risks. Although more or less analytical methods like FTIR and SEM help track physical and chemical changes, more comprehensive toxicity studies are needed to assess their environmental safety. When it comes to engineered microbial strains, such as PET-degrading *Pseudomonas* variants, strict biosafety, containment, and regulatory approvals must be ensured before field applications to prevent unplanned gene flow or may cause ecological imbalance. Finally, microbial degradation should be observed as a complementary tool within the comprehensive waste management hierarchy supporting but not replacing reduction, reuse, and recycling

strategies (Jayasekara *et al.*, 2023). In this background, PGPR can serve as a biological “finishing step” to clean up residues and mixed plastic wastes that other methods which cannot easily handle.

Control Strategies for Using Microorganisms

Microorganisms offer several innovative strategies for controlling plastic pollution through biological means. One of the most promising approaches is bioremediation, where selected microbial strains are applied directly to contaminated soils or water bodies to naturally break down plastics. Advances in enzyme engineering have further enhanced this process scientists are designing improved versions of key enzymes like PETase, which can degrade plastics such as PET more efficiently (Jayasekara *et al.*, 2023). In

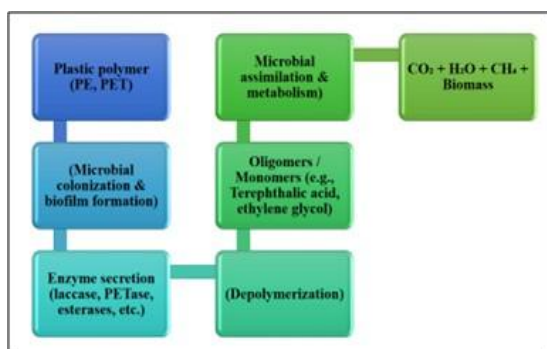


Fig. No. 1 Simplified Flowchart of the Process

addition, the use of microbial consortia, or mixed communities of different microorganisms (Ting & Sallahudin, 2025), has proven effective because the combined metabolic activities of various species often lead to faster and more complete degradation. Genetic engineering also plays a vital role, allowing researchers to modify microbes to boost their plastic degrading capacity or adapt them to harsh environmental conditions (Wei *et al.*, 2025). Finally, these biological tools are being translated into industrial applications, such as incorporating plastic degrading microbes into waste management systems, composting facilities, and bioreactors

(Jayasekara *et al.*, 2023), where they can contribute to a more sustainable and eco-friendly approach to plastic waste treatment.

CONCLUSION

Plastic pollution has become one of the most critical global environmental issues, as plastics such as polyethylene, polypropylene, and PET persist in soil and water for centuries due to their durable polymeric structure and resistance to degradation (Dhaka *et al.*, 2023). Improper disposal leads to microplastic accumulation, disrupting ecosystems, contaminating food chains, and posing risks to human health. To address this, scientists are exploring plant growth-promoting rhizobacteria and other microbes as eco-friendly agents for plastic biodegradation. These microorganisms secrete enzymes like PETase, laccase, cutinase, and peroxidase, which break down complex plastic polymers into simpler, non-toxic compounds such as carbon dioxide, water, and biomass. Some PGPR, including *Pseudomonas*, *Bacillus*, and *Aspergillus* species, can degrade common plastics while simultaneously enhancing soil fertility and plant growth by producing auxins, siderophores, and ACC-deaminase.

This dual functionality helps plants withstand pollution stress and promotes soil restoration (Tareen *et al.*, 2022; Zhao *et al.*, 2025). Recent studies highlight promising results with engineered and natural microbial strains that can degrade PET and polyethylene within weeks under laboratory conditions. However, microbial degradation remains a slow process and may produce intermediate fragments, making biosafety, regulation, and toxicity monitoring essential. To improve efficiency, researchers are using enzyme and genetic engineering, microbial consortia, and bioreactor-based applications to accelerate degradation (Jayasekara *et al.*, 2023; Wei *et al.*, 2025). Overall, PGPR-mediated plastic biodegradation represents a sustainable,



biologically driven complement to traditional waste management associate a circular bioeconomy by turning persistent pollutants into valuable resources while restoring soil and ecosystem health.

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