From Pollution to solution: Microbial Enzyme Engineering for PET Plastic Breakdown

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Abstract:

With global plastic production exceeding 400 million tons annually, polyethylene terephthalate (PET) has become one of the most persistent contributors to microplastic pollution in aquatic and terrestrial ecosystems. Its highly crystalline structure renders its highly resistant to natural biodegradation. Conventional remediation strategies such as incineration and landfilling are energy-intensive and environmentally unsustainable, highlighting the urgent need for biological alternatives.

This review examines advances in PET microplastic bioremediation, focusing on Microbial degradation pathways and enzymatic hydrolysis. Ideonella sakaiensis (currently classified as Piscinibacter sakaiensis), a bacterium capable of PET degradation through a synergistic dual-enzyme system involving PETase and MHETase. This Enzymes catalyze the sequential hydrolysis of PET into environmentally benign monomers.Emerging strategies including protein engineering and microbial consortia are being investigated to improve catalytic efficiency and scalability. Despite limitations, enzyme-assisted bioremediation shows promise for mitigating PET-derived microplastic pollution.

1. INTRODUCTION:

Microplastic, defined as plastic particles smaller than 5mm, have become a major Environmental concerns due to their persistence and widespread distribution in aquatic and terrestrial ecosystems. They originate from both primary sources and the breakdown of larger plastic materials. Among various polymers, polyethylene terephthalate (PET) is a significant contributor to secondary microplastics because of its extensive use in packaging and textiles. Its highly crystalline structure makes it resistant to natural degradation, leading to long-term environmental accumulation.

Recent studies indicate that microorganisms can interact with plastic surfaces through biofilm formation and enzymatic activity. In particular, Ideonella sakaiensis has shown the ability to degrade PET using PETase and MHETase enzymes, although its efficiency is limited under natural conditions. Understanding these processes is essential for developing sustainable strategies to manage microplastic pollution. Andrady, A. L. (2017).

2. OBJECTIVE:

- To study bioremediation mechanism for PET microplastic.
- Explore sustainable safe degradation of plastic with bacteria found in landfills.

3. SMALL PARTICLES, BIG PROBLEMS:

Microplastics are fine pollutants enter water, air, and even our food chain without being noticed. These particles harm marine life, affect human, and are difficult to remove once released. Therefore, reducing pollution at its source and spreading awareness is essential to protect our future.

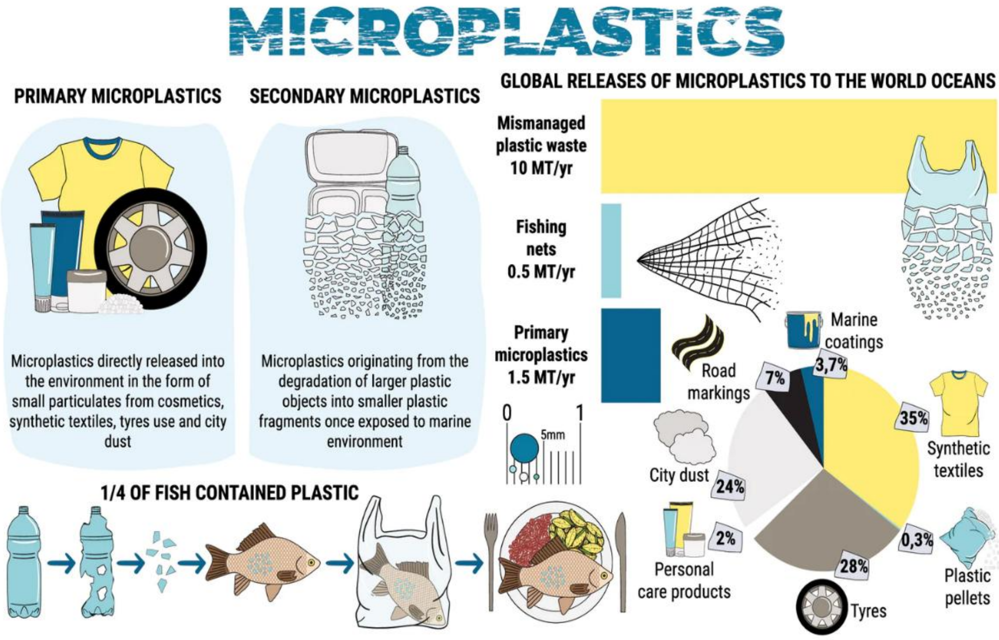

FIGURE : Sources of Microplastic

4. ABOUT POLYETHYLENE TEREPHTHALATE (PET):

- PET has higher global Production.
- High crystallinity → Environmental persistence.
- Forms microplastic, Non-Biodegradable.
- Accumulates in water, soil and sediments.

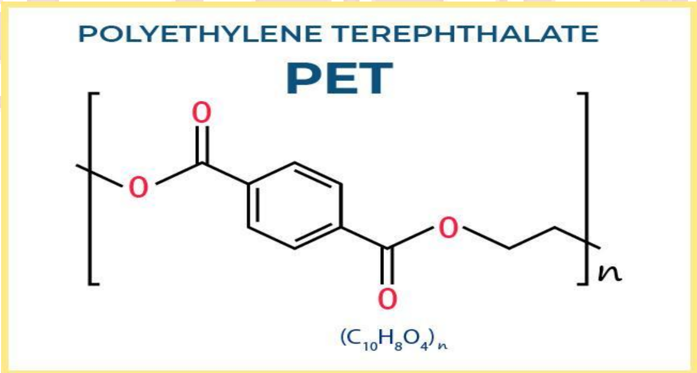

FIGURE : PET chemical Structure

5. MICROBE INCLUDED: (Ideonella sakaiensis)

Ideonella sakaiensis is a Gram-negative, aerobic, rod-shaped bacterium first identified in 2016 from a PET-contaminated recycling site in Japan. It is known for its unique ability to degrade polyethylene terephthalate (PET) by utilizing it as a carbon source. The bacterium secretes two key enzymes PETase and MHETase, (Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., ... & Oda, K. (2016), which breakdown PET into monomers, terephthalic acid and ethylene glycol. These compounds cab be further metabolized by the microorganism. While Ideonella sakaiensis shows effective degradation of low-crystallinity PET under controlled conditions, its efficiency remains limited foe high-crystallinity PET in natural environments. Despite this limitation, it represents a promising candidate for bioremediation and bio-recycling of plastic waste.

6. METHODOLOGY:

Relevant research papers were collected and analyzed. Information on Microplastic sources, PET, and microbial degradation was studied to understand environmental impact and possible solutions.

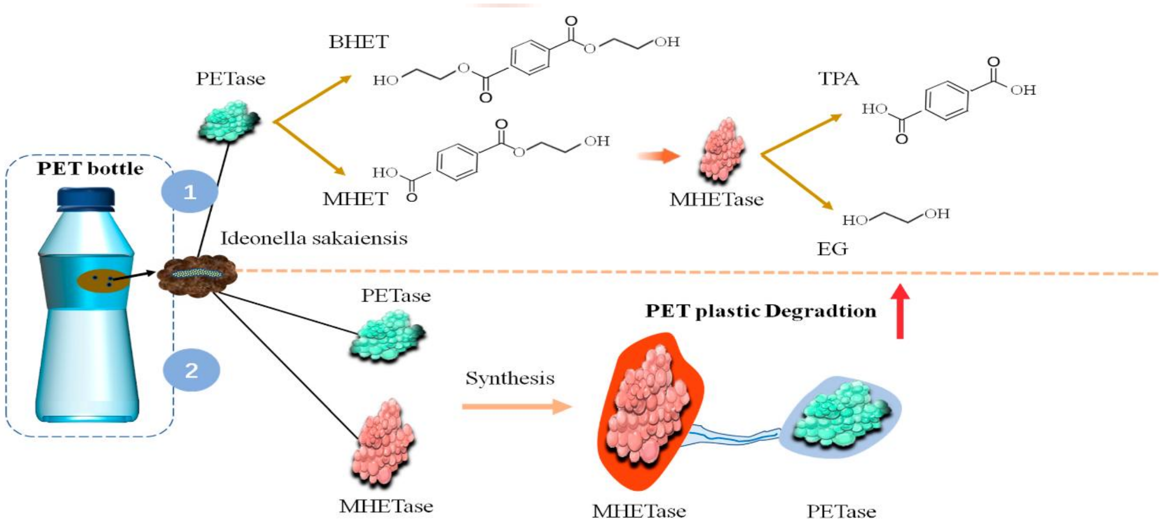

FIGURE: Cai, Zeming & Li, Minqian & Zhu, Ziying & Wang, Xiaocui & Huang, Yuanyin & Li, Tianmu & Gong, Han & Yan, Muting. (2023). Biological Degradation of Plastics and Microplastics: A Recent Perspective on Associated Mechanisms and Influencing Factors. Microorganisms. 11. 1661. 10.3390/microorganisms11071661.

7. RESULTS:

Microplastics are widely distributed in the environment, mainly originating from secondary sources. PET is a major contributor due to its high usage and resistance to degradation. Microorganisms such as Ideonella sakaiensis can degrade PET through enzymatic activity, (Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., ... & Oda, K. (2016), but the process is slow, especially for high-crystallinity PET. These findings indicate that while microbial degradation has potential, it remains limited under natural conditons.

8. CONCLUSION:

Microplastic those derived from PET, pose a significant environmental challenge due to their persistence and widespread presence. Although microorganisms such as Ideonella sakaiensis show the potential to degrade PET, the process remains slow and limited under natural conditions. Therefore, improved and sustainable strategies are required to effectively manage PET-based microplastic pollution.

9. FUTURE PROSPECT:

Future research should focus in improving PET degradation through enzyme engineering and the use if microbial consortia. Combining biological approaches with physical or chemical pretreatment may enhance efficiency. These advancements can support the developmental of sustainable strategies for managing PET-derived microplastic pollution.

REFERENCES:

1. Cassella, K., et al. *Bioremediation of Polyethylene Terephthalate with Ideonella sakaiensis [Slides]*. No. LLNL-TR-852191. Lawrence Livermore National Laboratory (LLNL), Livermore, CA (United States), 2023.
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3. Valamontes, Antonios. "Genetic Engineering and Metabolic Pathway Optimization of Ideonella sakaiensis for Enhanced PET Biodegradation." (2024).