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Review

Microbial degradation of plastic: A review on bacterial and fungal contributions

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Abstract

Plastic is a synthetic polymer that consists of high molecular weight. Plastic is prepared from organic compounds first derived from natural gas or renewable sources. There are different types of plastics: Polypropylene (PP), Polyethylene (PE), Polyethylene Terephthalate (PET), etc... The polymeric material takes long time for decompose leading to long term accumulation in landfills and oceans. To overcome the problem, researchers have researched the biodegradation of plastic by Enzymes, including bacteria and fungi, have been identified for their ability to degrade plastics under specific conditions. Recently in biotechnology, a Plastic eating enzyme was identified i.e PETase (polyethylene terepthalate hydrolase) from *Ideonella sakaiensis* in Japan. This review explores the mechanisms and potential applications of biodegradation of plastic waste and some factors that affect the biodegradation of plastic.

Keywords: Plastic, waste reduction, Plastic degradation, *Ideonella sakaiensis*, PETase coding gene.

INTRODUCTION

Plastic, a synthetic polymer characterized by its high molecular weight, forms long chains of repeating units. Its cost-effectiveness makes it a widely utilized material, particularly in the packaging industry. The elemental composition of plastic can include carbon, nitrogen, and bromine, among others. Common types of plastic encountered in everyday life include PET (Polyethylene terephthalate), PE (Polyethylene), and PC (Polycarbonate) (1,2,3).

Global plastic production has shown a consistent upward trend between 2020 and 2023, reaching an estimated 413.8 million metric tons in 2023. Annually, approximately 140 million tons of synthetic polymers are manufactured worldwide.

The exposure of plastic to high temperatures results in its combustion, releasing harmful toxic gases into the environment. Inhalation of these fumes poses significant health risks, potentially leading to lung diseases and cancer. Biodegradation presents a more environmentally sound approach to managing plastic waste. This process relies on the metabolic activities of microorganisms, primarily fungi and bacteria, which break down the plastic under the influence of various environmental conditions. Fungi, in particular, play a crucial role in the biodegradation of plastics under appropriate environmental stimuli(4).

Biodegradation of plastic

The biodegradation of plastic is the process by which microorganisms (such as bacteria, fungi, and their enzymes) break down plastic materials into natural substances like carbon dioxide, water, and microbial biomass. While most conventional plastics, like polyethylene and polystyrene, are highly durable and can persist in the environment for hundreds or even thousands of years, biodegradation offers a more sustainable alternative for their eventual decomposition(5).

Here are the key improvements and why they were made:

- **More concise and formal language:** "breakdown of plastic material by using microorganisms" is rephrased to "the process by which microorganisms... break down plastic materials."
- **Emphasis on the agents:** List bacteria, fungi, and *their enzymes* as the active agents in the process. Enzymes are crucial as they are the biological catalysts that perform the degradation.
- **Improved flow and clarity:** The sentence structure is smoother and easier to understand.
- **Stronger contrast:** The phrase "While most conventional plastics..." clearly highlights the challenge of traditional plastics and positions biodegradation as a solution.
- **More accurate timeframe:** "taken thousand of years to degrade" is softened to "can persist in the environment for hundreds or even thousands of years," which is a more accurate general statement.

S.no	Types of plastic	Thermal degradation	Photooxidative	Biodegradation
1	Polyethylene(PE)	Degrade above 300c Forming waxes and hydrocarbon	UV light causes chain Scission and embrittlement	Very slow; some microbes It can degrade PE over Decades (6)
2	Polypropylene(PP)	Starts at 270c produce propenegas	Degrade UV expouser	Slow, but some bacteria Brake it down(7)
3	Polyethylene Terephthalate(PET)	At 250c	UV light causes slow embritlement	Some microbes and Enzymes (Ideonella)(8)
4	Polycarbonate(PC)	At 280c produce biphenal A	UV exposed leads to Yellowing cracking	Not easy biodegradation (9)
5	Polyamide(Nylon)	Melt and degrade above 200c	Breake down in humid condition	Nylons enzyme(10)
6	Polylactide Acid(PLA)	Start degrade at ~ 170c	Decomposed in water	Rapidly degrade in Industrial composting Condition
7	Polystyrene(PS)	Breakdown at 300c Formin styrene monomer	UV exposed	Very resistant through Break it down by fungi

Various types of plastic degradation-comparison

Factors affecting biodegradation of plastic

The biodegradation of plastics depending upon the Environmental factors such as temperature, moisture, oxygen level and it have optimal PH higher temperature can increase the rate of biodegradation but extreme temperature can be inhibit microbial growth moisture it adequate moisture necessary for growth of microbials and biodegradation. The microorganisms have optimal PH range for growth and biodegradation(11).

Microorganisms and their role in degradation of plastic

Microorganisms are bacteria and fungi play a role of degradation of plastic breaking the large particle into smaller particles. The effect of microbes on their environment can be beneficial or harmful the plastic biodegradation depends on various factors like morphology, molecular weight. The enzyme that can be attach chemical bond and plastic leads to decomposed(12).

S.no	Microbes	Plastic type	Producing enzyme
1	Ideonella sakaiensis	PET(Polyethylene Terephthalate)	Enzyme like PETase, and MHETase
2	Pseudomonas spp	Polyurethene(PU)	Hydrocarbon degrading
3	Rhodococcus spp	Polyethylene(PE)	_
4	Aspergillus spp	Polyethylene	_
5	Fusarium spp	Polyurethane and Other plastic	Laccases

Ideonella skaiensis

Ideonella Sakaiensis is a bacterium the genus ideonella the family of bacteria is comamonadacea . It is a gram negative means they have thin peptidoglycan layer in their cell wall. It is capable of breakdown of plastic is Poliethylene terepthalate (PET) using carbon and energy source. It was first identified in 2016 by team of reaserchers led by koheioda of Kyoto institute and technology of keio university. The structure of bacteria it is a gram negative aerobic and rod shaped it have a single flagellum. It is a colourless smooth and circular. It vares size from 0.6 to 0.8 mm in width and 1.2 to1.5 mm in length.

The bacterium its able to degrade PET (polyethylene terephthalate) plastic. It was originally found in a PET bottle recycling plant in japan.The bacteria which growth of at temperature 30c the maintaining of PH around 7.0. It will used nutrients likes minimal salt medium with a carbon source. It is a aerobic so ensure oxygen supply ideonella sakaiensis produces two key enzymes like PETase (breaks PET into MHET mono (2-hydroxy ethyl) terephthalic acid). MHETase (further degrades MHET into terepthalic acid and ethylene glycol). The degrade of plastic depends on several factors including temperature, surface area bacterial concentration. In the lab condition 6 weeks to break down a thin PET film (0.2mm thick).In case complete degradation it can be take several moths for thicker plastic(13).

Plastic Degradation by *Ideonella Sakaiensis* by PETase Enzyme (breakdown PET into HET, MHET (mono(2 hydroxy ethyl sterepthalic acid, MHETase Enzyme (convert MHET into TPA and EG), TPA (Terephthalic acid) and EG (Ethylene glycol), Metabolism by *Ideonella sakaiensis* (used carbon source)

Aspergillus species can degrade plastic through enzyme activity. It is a genus fungi that has Early Discovered 15^{th}_16^{th} centuries. It was first described by the Italian physician and botanist Pietro Andrea Mattioli in 1544.It is a hyphae which are long branching filaments this species composed of chitin, glucan and other polysaccharides it contain various organelles include nuclei (14).

The role of Aspergillus in plastic degradation it can degrade plastic through enzymatic activity.The process involves surface colonization. The fungal spore attach to plastic surface and form biofilm. The secretion of enzyme such as laccases, cutinase, lipases and peroxidase, which break down polymer chain(15).

S.no	Aspergillus species	Types of plastic	Produced enzyme
1	Aspergillus niger	Polyethylene(PE) Polypropylen	Oxidase enzyme
2	Aspergillus flavus	Polyvinyl Cloride(PVC)	Peroxidase
3	Aspergillus terreus	Polyethylene	-

CONCLUSION

Plastic is a petroleum it used various purposes.PET (polyethylene terephthalate) is a widely used for strength, recyclability. Both bacteria and fungi offer potential solution for plastic degradation. While bacteria like *Ideonella sakaiensis* are highly specialized in PET breakdown, Fungi such as Aspergillus exhibit broader plastic degradation ability. Advancement in biotechnology and genetic engineer ring could further enhance microbial plastic degradation for environmental sustainability.

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