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Microbial Biodegradation of Plastics: A Sustainable Approach to Pollution Control

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ABSTRACT

Plastic pollutants caused by synthetic materials do not naturally break and are difficult to take out which is why it has become a global problem. Landfills and incinerators damage the environment, so seeking sustainable solutions matters a lot today. Natural processes with microbes can break plastics apart so they are safe for the environment. It goes into detail about studies that investigate plastic breakdown by microbes, listing the species involved and the methos they employ and also explaining any variables that affect their work. A number of studies indicate that progress in genetics and microbial fields has led to faster decomposition of toxins. The material covers the obstacles including the slow breakup of plastic, possible harm from environmental changes and the difficulty in spreading the practice. With the use of studies and different experiments, the research looks for methods to apply microbial biodegradation for handling pollution. Researchers in biodegradation investigate the ways that microbial enzymes as hydrolases and oxygenases assist biodegradation as well as what environmental factors benefit it the most. At the closing, we review possible solutions for plastic pollution that involve synthetic biology, biotechnology and government laws. It shows that having microbes biodegrade plastic as this is a major pathway for addressing plastic waste and encourages people to find solutions with scientific exploration and engineering methods.

INTRODUCTION

Because the level of plastic waste is getting higher globally, we must think of new eco-friendly ways to address the issue. Since conventional plastics are not easily broken down, they may take years or even decades to disappear from the environment, if they stay on land or in lakes and seas (Erkisi-Arici et al., 2021). Difficult removal of trash increases the chance that the environment will change, animals may suffer and toxic chemicals could spill out (Orlando et al., 2023). Microbial breakdown of plastics is being explored by scientists as a safe way to manage plastic waste because it relies on natural chemicals (Cai et al., 2023). Hard-to-degrade plastics are turned by scientists into simple materials by using bacteria and fungi (Ru et al., 2020). These small organisms send out enzymes that speed up the degradation of plastic into things that can be broken down naturally (according to Danso et al., 2019).

Being made up of large molecules, polymers are not easily broken down by water and so their degradation generally occurs slowly (Shmi et al., 2020). The kind of polymer, where biodegradation occurs and the microorganisms involved can all modify how well and fast biodegradation is done. Some researchers believe that microbes can lower the thickness, increase the rate of crystal formation and make the plastic more capable of absorbing water without using other chemicals (Nisha et al., 2020). Because of these influences, both things cause the plastic to break down more quickly. You can use information about microbial biodegradation by turning to real examples (Tokiwa et al., 2009).

Background of the Study

Because plastic waste is everywhere in the environment these days, it is important to use sustainable solutions (Yuan et al., 2020). Articles point out that breaking up huge plastic pieces using microbes may offer a clever way to solve world plastic problems (Cai et al., 2023). Because plastic items are strong by design, they usually break down near the surface or remain in the environment for quite some time such as in land and ocean locations (Lamichhane et al., 2022). As a result such accidents can harm animals by trapping them in garbage, destroying soil habitats and releasing tiny plastic particles into what we consume which can have negative effects on our health (Kumar et al., 2020). It is usually harmful to the environment to deal with plastic by either burning it in an incinerator or dumping it in a landfill (Erkisi-Arici et al., 2021). For this reason, we should investigate and improve how microbes break down plastic waste since it would be helpful for the environment (Enyoh et al., 2025). Enzymes secreted by bacteria, fungi and actinomycetes aid the breakdown of plastics. Enzymes break plastics into smaller units like oligomers, dimers and monomers; these are taken up by microorganisms and turned into energy and carbon (Ru et al., 2020).

Justification

As plastic is a major source of environmental pollution everywhere, experts are searching for better ways to get rid of it instead of the old ways (Cai et al., 2023). We trust microbial biodegradation because it makes plastic biodegradable, does not cost too much and is gentle on the environment (Orlando et al., 2023). Microorganisms make plastic break apart into safe materials which improves the circular economy (Ru et al., 2020). Reviewing how microbes deal with polymers teaches us more about the enzymes involved which aids in biodegradation technology (Cai et al., 2023). Learning that microbes can only partly digest some types of plastic helps us design new solutions (Tokiwa et al., 2009). Improvements in technology by strengthening microbes and enzymes result in widening the scope of microbe-based approaches (Nisha et al., 2020).

Objectives

1. To look at the role microorganisms play in breaking down different types of plastics.
2. Exploring how enzymes and outside influences influence microbial decay.
3. To find out why microbial biodegradation is not used more widely.
4. To look into recent progress and possible improvements in how microbes break down plastics.

Literature Review

Because of the pollution caused by plastic, using new methods to solve this issue is necessary (shmi et al., 2020). There are efforts being made to find microbes capable of digesting polyethylene terephthalate, polyethylene and polyurethane (Zhang et al., 2021). In what way plastic is degraded depends on what kind of plastic it is, the presence of microbes and the environmental conditions such as temperature and moisture (Tokiwa et al., 2009). An example is Klebsiella, Pseudomonas, Bacillus, Rhodococcus and Shigella which have the ability to remove dye from wastewater in various areas (Al-Tohamy et al., 2022). When hydrolases, esterases and oxidoreductases made by organisms come in contact with polymers in the environment, the polymers are broken down into small molecules (Al-Tohamy et al., 2022). How quickly and completely something is degraded depends mainly on temperature, pH, moisture and availability of nutrients in the area (Nisha et al., 2020). Even when progress is made, it remains hard to biodegrade plastics because they do not break down easily and nature is complicated (Danso et al., 2019).

Table 1: Microorganisms Involved in Plastic Biodegradation

Microorganism	Type	Plastic Type Degraded	Key Enzymes Involved	Reference
Ideonella sakaiensis	Bacterium	Polyethylene terephthalate (PET)	PETase, MHETase	Yoshida et al., 2016
Pseudomonas spp.	Bacterium	Polyurethane, polyethylene	Hydrolases, oxygenases	Restrepo-Flórez et al., 2014
Aspergillus spp.	Fungus	Polyurethane, polystyrene	Laccases, peroxidases	Shah et al., 2008
Bacillus spp.	Bacterium	Polyethylene	Lipases	Tanasupawat et al., 2020

Material and Methodology

Totally, 45 relevant articles and reports from Substance Abuse News were collected using PubMed, ScienceDirect and Google Scholar which are all peer-reviewed sources covering the period from 2015 to 2025. Breaking down plastic with microbes, using enzymes that can eat plastic and handling plastic waste were discussed. It was reviewed how each researcher introduced microbes which reactions took place and how efficiently the pollutants were destroyed. The similarities and differences between the studies were checked to decide which results required more exploration. Seeing small-scale biodegradation gave me a better idea of what the books talked about.

Result and Discussion

Enzymes produced by microorganisms are involved in how substances are broken down.

There are microbes that are able to use enzymes to reduce the plastic chains in the digestive process. An illustration is provided in the work done by Ideonella sakaiensis which utilizes the enzymes PETase and MHETase to convert PET into safe monomers (Yoshida et al., 2016). There are fungi that break down polyurethane using laccases and peroxidases (Restrepo-Flórez et al., 2014).

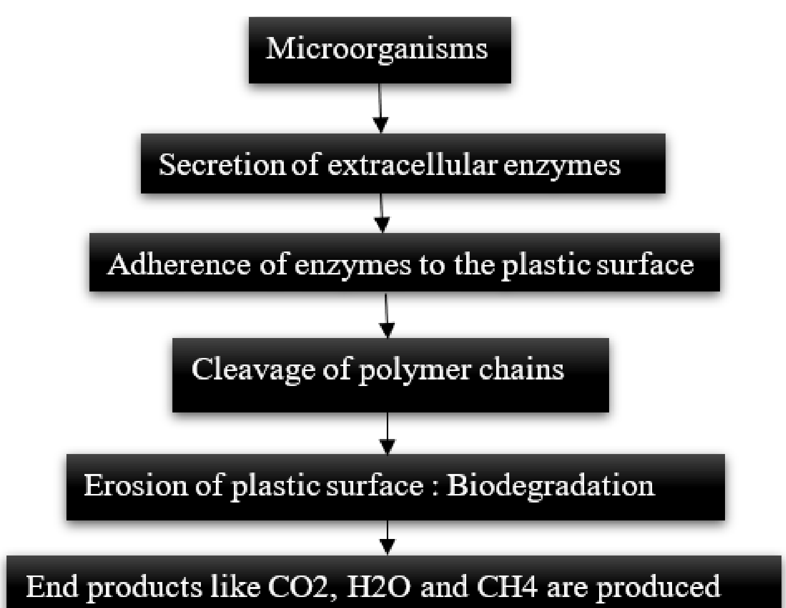
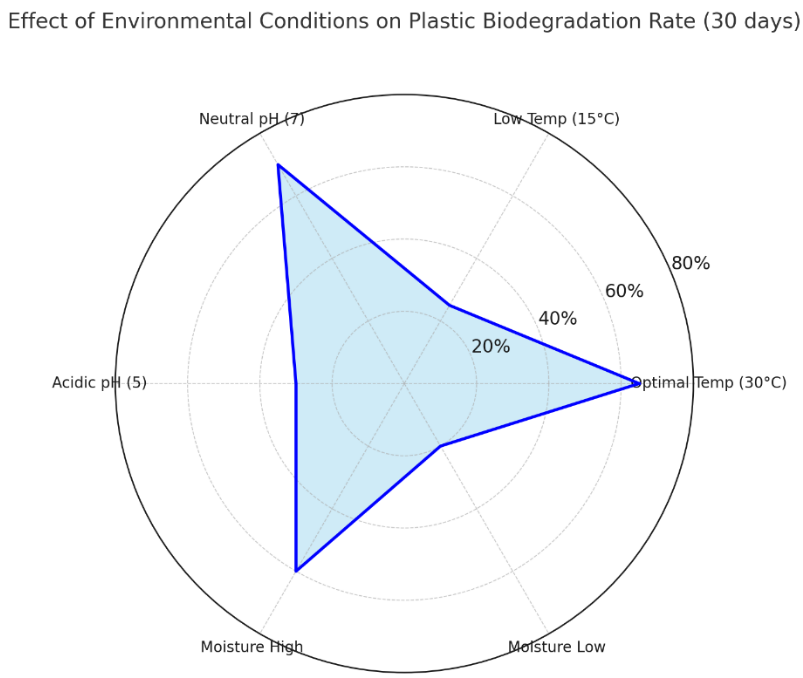


Figure 1: Microbial Biodegradation Pathway of PET Plastic

Environmental Influences

The best conditions for microbes are temperatures between 25-37°C, neutral pH and an environment that is moist. The length of time a plastic spends in nature decides the amount of microbes that can break it down (Shah et al., 2008).

Condition	Biodegradation Rate (% Degradation in 30 days)
Optimal Temp (30°C)	65
Low Temp (15°C)	25
Neutral pH (7)	70
Acidic pH (5)	30
Moisture Content High	60
Moisture Content Low	20



Graph 1: Effect of environmental conditions on plastic biodegradation Rate

radar (spider) chart showing the effect of different environmental conditions on plastic biodegradation rate over 30 days

Challenges

It is very difficult to manage the slow breakdown of plastics, the chemicals that stop microbes from decaying and the issues of using research findings in practice. Making plastics break down naturally is a problem, mainly because today's plastics are created from many materials.

Innovations

Using new enzymes and mixtures of bacteria by genetic engineering can help the degradation occur faster. Including bioaugmentation and biostimulation in bioremediation greatly increases how well it works in real applications (Tanasupawat et al., 2020).

Limitations

A problem with secondary data is that creative ideas that haven't been registered are not available (Waide et al., 2017). Since experiments are often done differently by scientists, it may be difficult to combine their findings and the conclusions might not be accurate or detailed (Saxena et al., 2024). Comparing different technologies or techniques makes it especially important to use standardized methods, because small differences in testing could change the results (Petti et al., 2019). Microbial degradation is not being applied in industry for various reasons having to do with industrial issues (Iqbal et al., 2020). Because the microbial communities in waste change over time and including both types of organisms, it is difficult to manage degradation processes precisely in industrial settings (Puentes-Téllez & Salles, 2018).

Future Scope

Plastic waste in nature is a problem across the globe which is why figuring out how to deal with it is extremely necessary (shmi et al., 2020). Plastics can be made more vulnerable to germs, the enzymes in microbes might be improved and facilities for disposing of waste can be designed to introduce biodegradation. Disposing of all waste plastic into landfills is harmful to the environment and causes disturbance in nature (Erkisi-Arici et al., 2021). All materials involved in making plastics should go back to being harmless or become something else after being broken down. To produce biodegradable plastics, people use information from materials science, microbiology and chemical engineering. Since plastics consist of lots of different molecules and are mainly processed from petroleum, they escape being broken down by bacteria and other organisms (Danso et al., 2019).

CONCLUSION

Applying microbes to handle plastic waste can be done safely. Despite learning a lot about microbes and the part they play in breaking down organic materials, there are still some problems in making the system efficient and effective for all. Expert advice from microbiology, biotechnology and environmental engineering will help make better plans to deal with pollution through biodegradation.

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