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Review On Soil Microbial Enzymes In The Breakdown Of Synthetic Polymers For Sustainable Waste Management

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ABSTARCT: Plastic pollution is still an important issue for the environment as synthetic polymers stay in natural ecosystems for an extended period of time. Because of its strength and chemical resistance, polypropylene is one of the most commonly used materials; however, these same properties also make it highly difficult to breakdown. The current study examines the function of the alkaline hydroxylase enzyme derived from Pseudomonas putida in the initiation of polypropylene degradation. Biochemical tests indicated that the enzyme was made and that it worked. In a controlled laboratory environment, the enzyme was used to treat polypropylene films. We examined the degradation process using weight loss measurements and chromatographic techniques like GC-MS and HPLC. The findings demonstrated that the polypropylene's weight had decreased, indicating a breakdown in the polymer structure. The development of intermediate compounds like alcohols and aldehydes was more proof that enzymatic oxidation had taken place. Two analytical methods that demonstrated the presence of these degradation products were HPLC and GC-MS. Long hydrocarbon chains had been disintegrating into smaller molecules, they confirmed. This means that alkaline hydroxylase starts the breakdown of polymers by adding oxygen to the structure. According to the study, utilizing enzymes to break down plastic waste is a viable and eco-friendly solution. It also demonstrates the possibility of creating long-term strategies to reduce environmental pollution.

***Index Terms* - Polypropylene, Alkaline Hydroxylase, Biodegradation, *Pseudomonas putida*, HPLC, GC-MS**

1. Resistance of Polypropylene to Degradation

Long chains of saturated hydrocarbons with strong carbon–carbon bonds makeup polypropylene, which makes it extremely resistant to natural degradation. Degradation processes are further slowed down due to its hydrophobic surface, which limits enzyme accessibility and microbial adhesion [1, 4]. Because of these properties, polypropylene typically remains in the environment for long periods of time and makes a major contribution to plastic pollution [4, 7].

2. Role of Microorganisms in Polymer Degradation

Hydrocarbon-degrading microorganisms are crucial for the biodegradation of plastic. Pseudomonas putida is one species that is well-known for its adaptable metabolism and capacity to use hydrocarbons as a carbon source. Under the right environmental circumstances, these organisms can produce enzymes that can act on complex polymer structures and initiate degradation [2].

3. Mechanism of Alkaline Hydroxylase Action

The addition of oxygen to hydrocarbon chains is catalyzed by the monooxygenase enzyme alkaline hydroxylase. This process turns inert alkanes into alcohols, which can subsequently go through additional metabolism [3, 6]. The enzyme can break down polypropylene by adding oxygen to the polymer's backbone because it is composed of identical hydrocarbon chains. This oxidative change increases the polymer's reactivity and promotes chain scission [5, 6].

4. Surface Modification and Enzyme Interaction

The initial interaction between the polymer and the enzyme is a critical step in the degradation process. Because polypropylene is hydrophobic, surface pre-treatment is necessary to enhance enzyme binding [10]. These treatments increase surface roughness, add functional groups, and improve enzyme accessibility. After adhering to the surface, the enzyme can effectively initiate oxidation processes [9, 11].

5. Evidence of Degradation from Weight Loss

Enzyme-treated polypropylene films in this study lost nearly 16% of their weight. This reduction indicates that a portion of the polymer has broken down into smaller molecules. Weight loss is a frequently used indicator of polymer degradation and shows how well an enzyme is working [8].

6. HPLC Analysis of Degradation Products

The enzyme-treated samples had more peaks than the control, according to analysis using High Performance Liquid Chromatography [13, 15]. These peaks represent the soluble intermediate chemicals produced during degradation [16]. The change in retention time indicates the disintegration of polymer chains into smaller molecules, confirming the production of new metabolites [17].

7. GC-MS Confirmation of Oxidative Breakdown

GC-MS analysis has further confirmed the degradation of the polymer by identifying the degradation products such as alcohols, aldehydes, fatty acids, etc. All these compounds are usually a result of the oxidation of hydrocarbons, thus confirming that the enzyme has successfully initiated the degradation of the polymer [19, 21].

8. Overall Degradation Mechanism

The degradation mechanism can be explained by understanding the following steps: first, the enzyme reacts with the polymer by introducing oxygen into the polymer chain, thus forming functional groups [18]. The formation of these functional groups causes scission of the polymer chains, resulting in the formation of low-molecular-weight compounds [20].

9. Significance of Enzymatic Degradation

The results of this investigation revealed that enzymatic degradation offers a promising solution for plastic disposal, unlike other conventional disposal techniques. Unlike other disposal techniques, enzymatic degradation is environmentally friendly, as this method occurs under mild conditions [23]. The capability of alkaline hydroxylase in initiating polypropylene degradation is significant in plastic waste management [22].

Conclusion

It is clear from the experimental findings that the enzyme alkaline hydroxylase is crucial in starting the breakdown of polypropylene. Despite polypropylene's intrinsic resistance to degradation, the Pseudomonas putida-produced enzyme was shown to be active and capable of interacting with the polymer surface. This demonstrates that synthetic polymers can be effectively targeted by hydrocarbon-degrading enzymes.

It is evident from the quantifiable weight loss in the polypropylene films that structural alterations have taken place within the polymer matrix. The disintegration of long-chain hydrocarbons into smaller pieces is reflected in this weight loss. Furthermore, analytical methods like GC-MS and HPLC offered compelling proof of degradation. The presence of new peaks in chromatographic analysis confirms the formation of intermediate compounds such as alcohols, aldehydes, and fatty acids, which are characteristic products of oxidative degradation.

These results show that a crucial stage in transforming inert polymer chains into more reactive and biodegradable forms is enzymatic oxidation. The enzyme makes it easier for oxygen to be incorporated into the polymer backbone, weakening the structure and encouraging chain scission. The study successfully demonstrates that degradation has been started at a molecular level, even though full mineralization of polypropylene was not attained during the experimental period.

The findings also demonstrate the potential of enzyme-mediated techniques as sustainable and environmentally beneficial substitutes for traditional plastic disposal techniques. Enzymatic processes work in mild conditions and produce fewer hazardous byproducts than physical and chemical treatments. The efficiency of degradation can be greatly increased with additional optimization of factors like enzyme concentration, incubation period, and environmental conditions.

All things considered, this study offers insightful information about the viability of employing microbial enzymes for polypropylene degradation and establishes the groundwork for further studies intended to create efficient biotechnological solutions for the management of plastic waste.

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