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**REVIEW ARTICLE**

**Biodegradation and Biotechnological Approaches for the Control of Plastic Pollution on Land and Ocean**

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**ABSTRACT**Nowadays, constantly increasing plastic pollution is the primary area of scientific research worldwide.The excessive useof this synthetic polymer has led to its accumulation in the environment. A large number of marine organisms are at risk because of plastic debris jeopardizing their survival and many are already at the stake of endangerment. The conventional plastic waste management techniques are inadequate as their by-products are also hazardous to environment and oceans. Microbes exposed to plastic waste and producing catalytic enzyme have proved to be one of the finest approaches to tackle this ever-increasing problem of plastic waste. This biodegradation occurs through various steps including biodeterioration and depolymerization. Recent advances in system biology and genetic engineering techniques can pave path towards better plastic degradation. This review highlights the toxic impact of nano and microplastic on environment and ocean and how futuristic research in biodegradation can solve the issue of plastic pollution.  
 **INTRODUCTION**

Plastic is a synthetic polymer of high molecular weight consisting of long hydrocarbon chains which are derived from petrochemicals [1]. The advancement in urbanization has increased the demand of plastic-based products. But the persistent nature of plastic has caused serious environmental threats. It is estimated that around 30-40% of plastic is produced for packaging purposes [2]. The countries which are generating plastic waste in abundance are China, US, Germany, Russia, Egypt and United Kingdom with about 59, 38, 14.5, 6, 5.5 and 5 million tons per year [3]. The common types of global plastic waste include Polyethylene terephthalate (PET), high and low-density polyethylene (HD-PE/LD-PE), polystyrene (PS) and polypropylene (PP) [4]. An energy efficient and eco-friendly approach is required for proper plastic waste treatment. Biodegradation has made its name when it comes to degrading plastic material efficiently. The micro-organisms (mainly bacteria) adhere themselves on the surface of plastic for their own growth and reproduction [5]. In 1970s, the first microbial colonization was reported when marine microbes and diatoms were found on marine debris. Microbial enzymes such as oxidoreductase, laccase and peroxidase have exceptional abilities in degrading the plastic polymer. They break plastic into its smaller components such as monomer, dimmers, and oligomers. These smaller components have the ability to pass through the cell membrane of micro-organisms and act as carbon and energy source [6]. Despite the significant results of biodegradation, it cannot be used on commercial scale due to slow processing time. Nowadays, scientists are working on modern biotechnological techniques which include genetic engineering, systems biology, and development of synthetic microbial consortium.

**How Plastic Effects Marine Life**

Plastic is ubiquitous in oceans so marine animals are attracted to plastic due to its color and because of algae that grows on freely floating plastic. Due to various reasons, plastic is easily bioavailable to marine biota including plantons, corals, mollusks etc. and enter food chain [7]. The aquatic life suffers from mortality, physical damage, sub lethal effects and various molecular modulation due to macro, micro and nano plastics. Large plastic waste disrupts marine living ecosystem by entangling and becoming stuck to the body of marine animals [8]. In the intestine and stomach of dead animals, plastic bag, bottle caps and fiber rope are easily and frequently found because they cannot differentiate much between plastic debris and their food/prey. The ingested plastic particles bio accumulates in biota fat tissues and internal organs. It leads to organ failure and disruption of metabolism depending on where the debris accumulates in body. It is reported that by 2050, 99% seabirds will be exposed to plastic pollution. Polyethylene has lethal effects when consumed by turtles and waterbirds [9].

**How Plastic Effects Human Beings**

Large amounts of toxic chemicals are used in the manufacturing of plastic products. Biomonitoring is a process which enables the measure of concentration of environmental contaminants in human tissues from multiple sources. This particular approach has proved to be very effective in detecting the presence of harmful chemicals used to develop plastic in human population [10]. The presence of phthalate, BPA as well as other additives that are used to manufacture plastic and its metabolite in human population has been detected by biomonitoring. Exposure to these chemicals via house dust is extensive [11]. For general population, ingestion, inhalation, and dermal contact are considered most important routes for exposure [12]. The male reproductive tract has proved to be majorly affected by exposure to phthalate. All these experiments were conducted on rats which were exposed to concentration slightly higher than those to which humans are generally exposed, but they resulted in the sever changes in the rat testis [11]. On the other hand, low doses of BPA have been found to stimulate insulin secretion followed by insulin resistance particularly in mice, less sperm production in rats and disruption of hippocampal synapses [11].

**Plastic Waste Management Strategies**

The two methods that are used for waste management are incineration and landfill. Both of these methods have many side effects on environment. Burning of plastic leads to the release of toxic gases and compound i.e., CO2 and dioxin that leads to air pollution [9]. Landfill requires large space for its proper functioning whereas incineration releases toxic gases as discussed before [13]. To deal with the waste problem, the strategy of reuse, reduce and recycle is widely adopted but it is not so effective. This method is only appropriate for postindustrial plastic waste but it is not suitable for plastic that is usually mixed with other organic or inorganic ingredients [14]. Thus, an eco-friendly and safe method is required to deal with the plastic debris. Biodegradation has proved to be an efficient and profitable method to deal with this problem worldwide [15].

**Biodegradation**

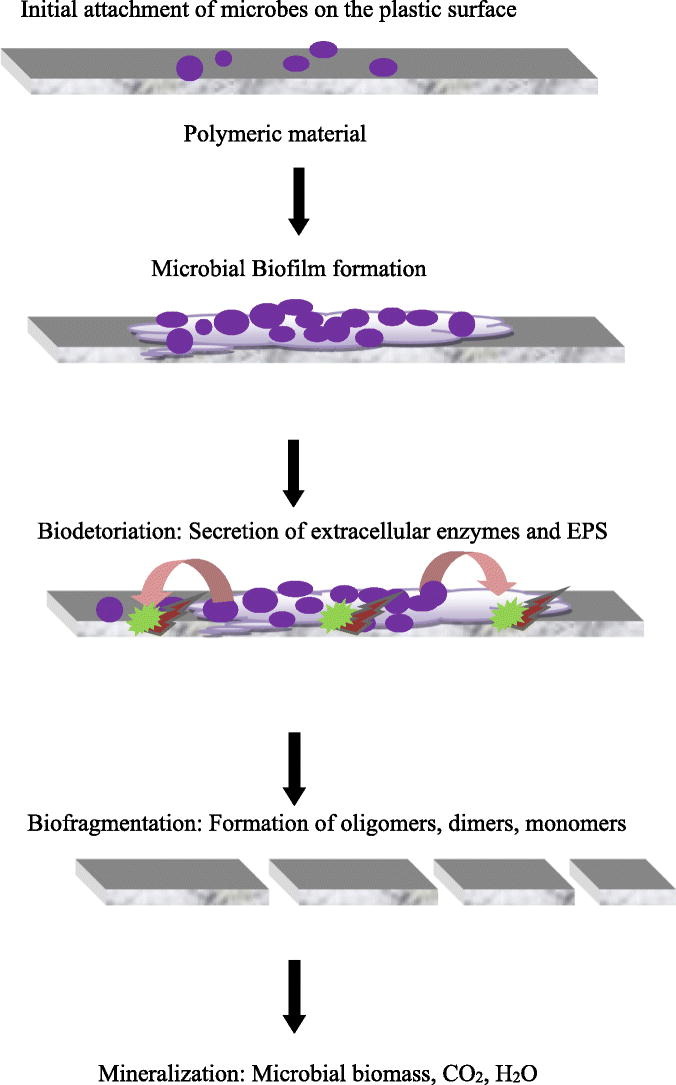
In order to offset the growing use of plastics each year, an efficient method of plastic waste processing is required, that is biodegradation. It is a technique for processing plastic waste that is safe, profitable, and economically useful. The potential of many microbes to dissolve plastic polymers is an asset that can be used to deal with issues emerging from increasing plastic waste accumulation every day. Extracellular and intracellular enzymes released from microbes are involved in the degradation of plastic polymers into smaller and safe fragments. Degradation of plastic C-C bonds directly by microbes are considered more effective. Degradation of plastic waste includes several steps: biodeterioration and depolymerization [16].

**Biodeterioration**

Biodeterioration is a process which is carried out by certain microorganisms on the plastic surface to alter or adjust plastic polymers [17]. Biofilms formed on the plastic surface by microorganisms can speed up the process. A biofilm is a form of community for living things. Microbes bind themselves and colonize an object's surface to form biofilms supported by an extracellular compound that they produce [13]. Microorganism-generated extracellular polymeric substances (EPS) help in breaking down the plastic surface [18, 19]. The plastic surface pores are breached by EPS, allowing the pores to expand. Microbes, bacteria, are enhanced to harm plastic polymers, to form holes and to facilitate the physical degradation of plastic polymers [19, 20]. Biofilms may also be involved in changing the pH of plastic polymers causing changing in microstructures [19].

**Bio fragmentation**

Bio fragmentation or depolymerization by depolymerase enzymes of the plastic constituents is carried out. The products of this reaction may be in the form of oligomers, dimers, and monomers simpler-than-polymer. Depending on the presence of oxygen molecules in the metabolism, they can be further processed. Microbial biomass, CO2, and H2O will be provided by aerobic degradation of those components. Although anaerobic degradation transforms these ingredients into microbial biomass, CO2, H2O and CH4 or H2S. The decomposed elements are then mineralized [17].



**Figure 1:** Schematic Illustration of plastic biodegradation by microorganisms. **Adapted from** [Anjana, Hinduja [21]](#_ENREF_41).

**Factors Affecting microbial degradation of plastics**

Factors such as environmental conditions, temperature and pH highly influence the activity of plastic degrading microorganisms with soil being the most important factor in environmental conditions. Microbes strongly rely on water content present in the soil which is necessary for their activation [22]. As the content of the moisture increases, hydrolytic breakdown of microbes becomes faster. However, there is a decrease in potential of enzymes involved in degradation as the temperature increases. Several polymers possess high melting point and thus are less likely to degrade. The speed of hydrolytic reaction is affected by the pH transition. The microbial growth rate is affected by the pH shift and affects the rate of degradation [23].

**Bacterial Strains capable of plastic biodegradation**

As compiled in table 1, several plastics that degrade bacteria have been widely documented by researchers. Some of the PE degrading bacteria are including B. subtilis and P. fluorescens isolated from garbage soil [24]. *A. borkumensis* from marine plastic waste [25]and *B. nedei* from LDPE contaminated soil [26] were grown in their respective mediums and showed 3.5% and 36.07% plastic weight loss indicating high efficiency of *B.nedei*. Plastic weight loss from 17-20% were observed in *Streptomyces* and *O. anthropic* isolated from soil [27, 28]. *B. cereus* and *S. globispora* isolated from mangrove sediment grown in mineral broth showed 11-12% PWL after 40 days of incubation [29].

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| --- | --- | --- | --- | --- | --- | --- |
| **Plastic types** | **Bacteria** | **Source** | **Plastic Weight Loss (PWL)** | **Media** | **Incubation Time** | **References** |
| Polyethylene (PE) | *Bacillus subtilis* | Garbage  Soil | 32% | Culture Broth Medium | 1 month | [24] |
| *Pseudomonas*  *fluorescens* | Garbage  Soil | 22% | Culture Broth Medium | 1 month | [24] |
| Low density polyethylene  (LDPE) | *Alcanivorax*  *borkumensis* | Marine Plastic Waste | 3.5% | Liquid Medium Containing 0.05% Hexadecane | 80 days | [25] |
| *Bacillus nedei* | LDPE Contaminated Soil | 36.07% | Mineral Agar | 2 months | [26] |
| High density polyethylene  (HDPE) | *Streptomyces* | Soil | 17% | ATCC medium | 1 month | [27] |
| *Ochrobacterium*  *anthropi* | Landfill soil | 20% | Mineral Salt Broth | 45 days | [28] |
| Polypropylene  (PP) | *Bacillus cereus* | Mangrove  Sediment | 12% | Mineral  Broth | 40 days | [29] |
| *Sporosacrina*  *globispora* | Mangrove  Sediment | 11% | Mineral  Broth | 40 days | [29] |

**Table 1:** Plastic Degrading Bacteria

**Mechanism of Plastic Degradation by Using Algal Strains**

The use of algal strains can also prove efficient for plastic degradation. Algae can colonize on polyethylene top surface in contaminated or sewage water whereas these colonizing algae are non-toxic and very less hazardous. Algae then produce enzymes such as ligninolytic and exopolysaccharide which plays a basic role in degrading plastic. These enzymes collaborate with macromolecules which are present at the top surface of plastic which activates biodegradation [30]. Fouling, penetration, hydrolysis, corrosion and degradation are the procedures involved in plastic biodegradation by algal strains. In some experiments it was concluded that *Anabaena spiroides* degrades highest percentage of plastic disposals approximately 8.18%, whereas *Navicula pupula* degrades almost 4.44% and *Scenedesmus dimorphus* degrades 3.74% [13].

**Synthetic Biological Approaches for Plastic Bioremediation**

**Microbial Consortium**

The symbiotically existing function-based microbial species are called microbial consortium and the researchers are exploring the potential and reprogramming the functionality of members of the microbial consortium for specific approaches, in particular the bioremediation of pollutants. As per the need for experimentation, the microbial consortium is also carefully optimised and organized [31]. Biodegradation using natural microbial consortiums, however, faces some limitations, such as the efficiency of bioremediation remains too poor due to microorganisms' survival difficulties in polluted environments, microbial cooperation and communication, etc. [32].

**Genetic Engineering Approach**

Genetic engineering technique alters the genetic material of the microbial cells to increase their efficiency for biodegradation of plastic contaminants which is present in the environment.Recombinant DNA technology facilitated to evolve the microbial potential by finding the genes for metabolizing the xenobiotic compounds and transforming them into suitable host microorganisms using appropriate vector under the tight control of promoters. *P*. *putida* and *Nitrosomonas* *europaea* are the most common microorganisms used for bioremediation purpose [33].

**Gene Editing Tools**

Gene editing tools have been applied for the genome engineering of plants, animals, and microorganisms for obtaining function specific gene expressed. For researchers, the evolution of Zinc finger proteins, TALENs, and more recently, CRISPR/Cas9 makes the genetic engineering approach very straightforward. They can grill the function of the genome and can be used clinically to correct or introduce mutations to increase the microbial potential for bioremediation [34].

**CONCLUSIONS**

Biodegradation of plastic waste using plastic degrading bacteria is a valuable treatment of plastic waste which must be carried out in order to preserve the environmental quality of the problems caused by plastic waste. This method has less or no side effects that pollute the environment. Some enzymes such as laccase and lipase produced by many microbes are involved in plastic biodegradation through several steps. The potential use of multiomics and the synthetic microbial community would make the processes of plastic bioremediation more successful. The long-term fate of nano and micro plastics in natural and industrial environments needs broader study. Thus, as long as complete mineralization of the biopolymers is achieved, further studies will contribute to the selection of suitable raw materials that can lead to the minimization of solid waste.

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