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Eco Safe Assimilation of Plastic Wastes by Microbes and Biodegradable Alternatives: A Review

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Abstract

Lack of degradability and the closing of landfill sites as well as growing water and land pollution problems have led to concern about plastics. In the past few decades, the use of plastics has enormously increased, mostly used for food packaging. Ironically, the most preferred property of plastics – durability – exerts also the major environmental threat. With the excessive use of plastics and increasing pressure being placed on capacities available for plastic waste disposal, the need for biodegradable plastics and biodegradation of plastic wastes has assumed increasing importance in the last few years.

Finding eco safe degradation processes is one of the future priorities for the researches. The degradation is very crucial as it leads to certain environmental pollution more often soil, water, and air pollution. More specifically it is necessary for the plastics disposals near the aquatic ecosystem. Non biotic degradations can lead to biological problems. So, the better solution is to dispose eco-safely and degrading biologically. The biological degradation includes the assimilation by certain enzymes produced by microbes and warms.

Biodegradable plastics can be the ideal solution of plastic's excessive durability that causes several environmental pollutions. The need to create biodegradable alternatives is because they can reduce the pollution levels to certain extents. Mostly their disposal is much easier and safe for environment. This article mainly suggests the possible eco-friendly ways to dispose plastics as well as the better biodegradable alternatives and bioplastics for future.

Keywords: Biodegradation; Bioplastics; Polyethene; Polylactic acids; Starch blends

Introduction: The need of plastic biodegradation and degradable alternatives

Developments in science and technology, especially over the last two decades, have increased the number of synthetic polymers produced worldwide each year. Each year approximately 140 million tons of synthetic polymers are produced [1]. Plastics are manmade long chain polymeric molecules [2]. The word plastic comes from the Greek word “plastikos”, which means ‘able to be molded into different shapes [3]. With time, stability and durability of plastics have been improved continuously, and hence this group of materials is now considered as a synonym for materials being resistant to many environmental influences [4].

The plastics we use today are made from inorganic and organic raw materials, such as carbon, silicon, hydrogen, nitrogen, oxygen and chloride. The basic materials used for making plastics are extracted from oil, coal and natural gas5.Enormous production and utilization of plastics leads to accumulation in the environment. Since they are not easily degraded by microorganisms, today they have become the serious source of pollution affecting both flora and fauna.in the absence of efficient methods for safe disposal of plastic waste these synthetic polymers accumulate in the environment posing an ever-increasing ecological threat to terrestrial and marine wild life [1,6]. The complete natural degradation of plastic takes more than several decades, which is a long-time process. The recent researches shows that the biodegradation of plastic wastes by certain microorganisms could be a viable solution because it can reduce the pollution level to a certain extent.

Biodegradable plastics are biopolymers that can be decomposed by the action of living organisms, usually microbes, into water carbon dioxide, and biomass [7]. Biodegradable plastics are commonly produced with renewable raw materials, micro-organisms, petrochemicals, or combinations of all three [8]. Their polymer chains may also be broken down by nonenzymatic processes such as chemical hydrolysis. Due to the property of fast assimilation in comparison to plastic wastes, they drown the attention of scientist. The notable point is, not all biobased polymers are biodegradable, e. g., crystalline poly (lactic acid) (PLA) is virtually non-biodegradable just like cellulose ester derivatives. The recently discovered polythioesters [8,9] are also not biodegradable [10]. The common biodegradable plastics are Polyhydroxyalkanoates (PHA), Polylactic acids (PLA), Starch blends, cellulose based plastics (CBP), Lignin based plastics (LBP).

Target markets for BPs include packaging materials (trash bags, wrappings, loose-fill foam, food containers, film wrapping, laminated paper), disposable nonwovens (engineered fabrics) and hygiene products (diaper back sheets, cotton swabs), consumer goods (fast-food tableware, containers, egg cartons, razor handles, toys), and agricultural tools (mulch films, planters) to enhance the application level of biodegradable alternatives [11].

Synthetic Plastic Wastes Accumulation: Potential Cause of Environmental Pollution

Harmful effects on marine ecosystem

The tremendous use of plastic in this era of science and technology has leads to certain environmental pollution most often soil and water pollution. According to an IUCN report, over 300 million tons of plastic are produced every year for use in a wide variety of applications. While plastics typically constitute approximately 10 per cent of discarded waste, they represent a much greater proportion of the debris accumulating on shorelines. Polyethylene (PE) was proportionally dominant in all environmental compartments, followed by polypropylene (PP) and polystyrene (PS) Plastic debris poses considerable threat by choking and starving wildlife, distributing non-native and potentially harmful organisms, absorbing toxic chemicals and degrading to micro-plastics that may subsequently be ingested [12]. The increased occurrence of plastics in marine ecosystems mirrors the increased prevalence of plastics in society, and reflects the high durability and persistence of plastics in the environment.

Due to its resistance to degradation, most plastic debris will persist in the environment for centuries and may be transported far from its source, including great distances out to sea. Land- and ocean-based sources are the major sources of plastic entering the environment, with domestic, industrial and fishing activities being the most important contributors. By the end of the 20th century, however, plastics were found to be persistent polluters of many environmental niches, from Mount Everest to the bottom of the sea. Ocean gyres are particular hotspots of plastic waste accumulation.

A large number of marine species is known to be harmed and/or killed by plastic debris, which could jeopardize their survival, especially since many are already endangered by other forms of anthropogenic activities. Marine animals are most affected by the entry and importation of plastic waste. Other lesser-known threats include the use of plastic waste by invader species and the absorption of polychlorinated biphenyls from infiltrated plastics. Not only is the plastic unpalatable, but also the tiny visible pellets that are less visible at the threat of marine objects. Threats to marine ecosystems are far higher than any other species. One of the most common reasons behind plastic is that it degrades before then in any other environment. The plastic is sometimes subdivided into tiny particles known as microplastics.

Plastic is dumped in the ground, and in the open sea. But the ocean these days has become a garbage dump for plastic because without much concern for the loss or harmful effects on the animals we dump there. Basically, plastic collections are most prevalent in the oceanic region near urban areas at that time in those of rural or undeveloped areas. The longevity of plastic is estimated to be hundreds to thousands of years old, but it is probably very long in the deep ocean and in areas not above ground. Plastic waste poses a serious threat by suffocating and starving wildlife, distributing non-native and potentially hazardous materials, absorbing toxic chemicals and degrading subsequent small plastics. Well-conducted annual coastal and marine studies have shown that the tendency for mega- and macro-plastic accumulation rates is no longer the same: stable, growing and declining styles have been reported.

The types of plastic waste in various aquatic environments were tested to find a global framework for plastic waste disposal and collection, appropriate for strategies to reduce plastic pollution in aquatic environments. Packing and consumer products were the most common product categories on the rivers, while fishing gear was most prevalent in the sea. Plastics from electronics, construction and construction, and transportation are rarely seen. In polymers, polyethylene and polypropylene have contributed significantly to pollution in all areas. The highest variations in polymer composition were found in marine and freshwater environments. It is therefore said that a large portion of plastic garbage collects here. The transport of plastic waste and collection patterns is significantly affected by quantity, surface area, and plastic size [14]. The direct movement of plastics in water, or the rate of sedimentation, is greatly affected by three factors: density, surface area of polymer, and particle size [15,16]. Marine wildlife is affected by plastic pollution by trapping, importing, accumulating, and changes in the integrity and functioning of habitats. While macroplastic debris is a major contributing factor, both micro- and macrodebris are incorporated into many marine species. Impacts on marine wildlife are now well established in many taxa, including [17,18,19] mammals, seabirds [18.20], sea turtles [21-26], fish [27-31]. The plastics found in the sea can be divided into 2 major types depending on their origin. 'User-plastics' are highly visible and contain personal items for personal use, such as plastic bags, cups, bottles, antique items, ropes and nets. These items are often commercially disposed of and fishing although some come from rivers and seas to dispose of landfill. Large plastic objects are often broken into smaller pieces commonly seen at sea [33].

Hazards to Terrestrial Ecosystem

More than 400 million tons of plastic are produced worldwide each year. It is estimated that one third of all plastic waste ends up in the ground or in freshwater. Most of this plastic breaks down into particles of less than five millimetres, called microplastics, and then decomposes into nanoparticles, which are less than 0.1 micrometer in size. In fact, microplastic contamination of the earth is much higher than marine microplastic pollution - an average of four to 23 times, depending on the environment. Sewage, for example, is an important factor in the distribution of microplastics. In fact, 80 to 90 percent of the particles contained in faeces, such as those from textiles, remain in the mud. Sewage sludge is commonly used in fields as fertilizer, which means that several thousand tons of microplastics are stored in our soil every year [34].

The physical and natural anthropogenic effects on the Earth System have reached a level similar to that of natural geophysical processes [35]. As a result, human activities are among the most important factors contributing to ecosystem operations and biodiversity threats [36]. The feature of a person's business feature is the widespread presence of plastic [37].

The nature of the combined microplastic effects can affect the soil through physico-chemical changes in soil structure and construction, resulting in the cycling of water and the ecosystem operating in the earth's systems and various plant-based ecosystems [38,39]. In this context, microplastic-driven changes in the hydrologic properties of the soil can affect the soil for biodiversity, as well as potential impacts on major symbiotic organizations in terrestrial ecosystems, such as mycorrhizal [40] and N-fixing [41] Associations. Thus, plastic as a whole can be considered the most obvious and common cause of significant environmental pollution and is harmful to animals. The best solution for reducing plastic waste is to reduce its natural degradation so that the recycling will not create environmental pollution.

Recent research shows that plastic can be contaminated with certain bacteria that do not have harmful effects. Reducing plastic base from germs can be a very effective and safe way to degrade.

Polymer's Assimilation by Microbes: An introduction

The destruction of plastic bacteria has been reviewed by [1,42,43] studies, which have reported abiotic and biotic (microbial) degradation of a wide range of polymers. The *Actinomycete rhodococcus* ruber [44] and the fungus *Penicillium simplicissimum* [45] have been shown to produce foreign enzymes that can reduce the degradation of PE, but also the thermophylic bacterium *Brevibacillus borstelensi*s [46] and Streptomyces sp. [47]. Polyhydroxyalkanoates (PHA), among them polyhydroxybutyrate (PHB), are composed of many chemicals; PHA depolymerase found in Pseudomonas stutzeri, Alcaligenes faecalis and Streptomyces sp. [1, 43, 48,49]. PHA-damaging fungi are separated from the soil and marine environments and especially Basidiomycetes, Deuteronomycetes (Penicillium and Aspergillus) and Ascomycetes [50] Polycaprolactone (PCL) are synthetic polyester that is easily degraded by microorganisms, among them the bacterium alum bacterium aluminum bacterium Polylactic acid (PLA) is a polymer commonly used in decaying plastics; its reduction by a thermophilic bacterium (*Bacillus brevis*) was reported to be [53], with only two species of the fungus *Fusarium moniliforme* and *Penicillium roqueforti* [50,43]. Compared to other polymers, PLA degradation is slower and less prone to microbial attack [43].

The immune system can also be improved with some treatment before exposing the virus. Abiotic factors such as UV irradiation, oxygen, temperature, and the presence of chemical oxidants, therefore play an important role in reducing PE and PP in the environment. The high molecular weight of synthetic polymers with repetitive hydrophobic units determines their water resistance in preventing the rapid formation of microorganisms [54].

How this works, viruses associated with degradation of enzymes break down the bonds that exist between two monomeric units. By hydrolysing bonds reduce polymers into smaller molecules. Although the disinfection process is a slow process but it should be considered because it does not harm the environment.

Overview of Biodegradation of Polymers

Polymeric products emitted from nature can be physically, chemically and biologically degraded or a combination of these elements due to the presence of moisture, air, temperature, light (image-degradation), high-energy radiation (UV, γ-radiation) or microorganisms (bacteria or fungi). Chemical and physical degradation rates are higher than those of natural disasters. Also, physical and chemical degradation facilitates microbial degradation and complete mineral degradation of polymer occurs due to biodegradation, which is usually the last step [24,25].

Mechanism of Biodegradation

Biodegradation of polymers involves following steps:

1. Attachment of microorganism to the surface of the polymer
2. Growth of microorganism utilizing the polymer as the carbon source
3. Primary degradation of the polymer and
4. Ultimate degradation

Microorganisms can adhere to the surface, if the polymer surface is hydrophilic. Since PP and PE have only CH2 groups, these areas are hydrophobic. Early physical or chemical degradation leads to the formation of hydrophilic groups on the surface of the polymer resulting in more hydrophilic (the incorporation of hydrophilic groups also reduces further strength). When the body attaches itself to the surface, it begins to grow by using polymer as a source of carbon. In basic degeneration, the main chain is cut, resulting in the formation of low-density fragments (oligomers), dimers or monomers [24]. Deterioration is caused by additional cellular enzymes secreted by the body. These low-weight compounds are also used by bacteria such as carbon and energy sources. Small oligomers may also enter the body and merge. The final products of decomposition are CO2, H2O and biomass under aerobic conditions. Anaerobic microorganisms can also degrade these polymers under anoxic conditions. The main products are CO2, H2O, CH4 and biomass under methanogenic or H2S, CO2 and H2O under sulfidogenic conditions. Environmental factors determine the group of microorganisms and the degenerative process involved. The final recycling of polymers can take a few hundred years [24-28]. Additives, antioxidants and other stabilizers added to commercial polymers can be toxic to organisms or slow down biodegradation.

Factors Affecting Biodegradability

The chemical separation of the polymer is actually determined by the following important physical and chemical factors:

1. The availability of active groups that increase hydrophilicity.

2. Size, molecular weight and polymer size.

3. Number of crystalline regions and amorphous regions.

4. Strength of structure such as uniformity or presence of branch in polymer.

5. Presence of easily breakable bonds such as ester or amide bond as opposed to carbon-carbon bond.

6. Cell formation (combination) as well.

7. The nature and form of the polymer form such as whether it is in the form of films, tablets, powders or fibres.

Biodegradation of Polyethene

Polythene is one of the most widely used polymers. Used for packing, household items and others. It is much cheaper than other polymers making it easier to use. Several previously published papers report on the natural increase in polyethylene and its composition (Table 1).

Title of the Paper	**Polymer**	**Organism**	**Analytical techniques used**	**Observation**	**Reference**
Electret-thermal analysis to assess biodegradation of polymer composites	LDPE/starch	Bacteria *Bacillus, Clostridium & micrococcus* Fungi *Aspergillus, Penicillium* & *Mucor*	DSC, FTIR, SEM & Physico-Mechanical testing	Biological erosion of 13 polyethylene by oxidative process	[59]
DSC, FTIR characterization of biodegradationof polyethylene	Polyethylene	Fungi *A. niger*	DSC & FTIR	Decreased amorphosity of the sample and relative intensity of carbonyl bond formation	[60]
Colonization, biofilm formation and biodegradation of polyethylene by a strain of *Rhodococus rubber*	LDPE blends	*Rhodococus rubber*	FTIR, SEM & weight loss	Carbonyl index reduced 66%, enrichment medium supplement with 2% mineral oil showed 50% degradation after 30 d incubation	[61]
Synergistic effect of combining UV sunlight-soil burial treatment on the biodegradation rate of LDPE/starch blends	LDPE/starch blends	Soil organisms	DSC, FT-IR, tensile strength & SEM	Starch blend PE exposed UV 14 radiation & soil burial samples showed 66% degradation	[62]
Acquired biodegradability of polyethylene containing pro-oxidant additives	LDPE/HDPE Blends	*R. rhodochrous, N.asteroids, Aspergillus flavis, C. cladospoides*	ATP,ADP assay, Size exclusion chromatography, Micr oscopy techniques & NMR	R. rhodochrous & N. astroides found to be most active for molecular weight reduction	[63]
Effect of compatibilizer on the biodegradation and mechanical properties of high content starch /low density polyethylene blends	LDPE/starch blends	Soil organisms	Mechanical properties, weight loss, melt flow index & SEM	65% weight loss increase in 14 d	[64]

Title of the Paper	Polymer	Organism	Analytical techniques used	Observation	Reference
Polyethylene biodegradation by developed *Penicillium-Bacillus* biofilm	Polyethylene	*P. frequentans B. mycoides*	Microscopy, weight loss, gas chromatography	Weight loss of pre heated polyethylene treated with fungi showed 7.150% & without preheating treated with showed 6.657%	[65]
Photo biodegradation of low density polyethylene/banana starch films	LDPE/starch blends	Soil micro organisms	FTIR, tensile strength elongation & weight loss	Increased carbonyl index and Tensile strength & elongation at break increased in LDPE/starch blends	[66]
Biodegradation potential of some barrier-coated boards in different soil environments	Polyethylene & Polyester	Soil micro organisms	DSC & FTIR	Under soil burial condition PE Polyester blends affects mechanical behavior.	[67]

Table 1: Showing Biodegradation of different polyethene blends [56]

The degradation of polythene begins with the attachment of bacteria to their surface. The various bacteria mentioned above and the fungi that reduce wood produce foreign enzymes that lead to polythene degradation. In fungi that degrade wood, the extracellular enzymatic complex (lignolytic system) contains peroxidases, laccases and oxidases that lead to the production of extracellular hydrogen peroxide [59].

Future Need

The state of polythene contamination should be carefully evaluated. A campaign to raise awareness of polythene pollution should be promoted at the community level. The idea of using alternative methods should be encouraged. In degrading polythene bacteria, once the genetic mutation factor is known, it can be reused over other viruses to degrade polythene.

After field testing of the most effective virus, it should be repeated in large quantities to decompose polythene at commercial level.

Biobased & Biodegradable polymer Alternatives of plastic

The term "biobased polymers" applies not only to polymeric materials but also to natural materials embedded in high-density chemical polymers and / or biological methods. Therefore, biobased polymers consisting of various polymers are made from renewable resources and CO2, biopolymers, e.g. Therefore, not all polymers are chemically separated from biodegradable, e.g. [68,69] newly discovered polythioesters are also non-biodegradable [70]. However, these types of biobased polymers are important because one needs non-perishable and non-perishable polymers that can be synthesized from renewable resources. In addition, the concept of non-perishable plastics produced from renewable resources is carbon neutral '. In this article, we focus on biobased and biodegradable polymers, with thermoplastic properties.

The main reason for the initial interest in perishable plastics is that non-perishable plastic packaging poses a major problem of waste disposal. As a result, much work has been done in the last 30 years in the manufacture of perishable plastic packaging. Various biopolymers, biosynthetic polymers, chemosynthetic polymers, their compounds and their compounds have been investigated by packaging systems. In order for decaying plastics to be suitable for food packaging, certain operational methods need to be fulfilled such as optimal strength and adaptability, non-toxicity, oxygen resistance, good resistance, durability during wide-temperature storage, and low cost both building materials and processing technology (Table 2).

Category	Bio based polymer	Producer	Trade name
Bio-Chemosynthetic polymers	Poly(lactic acid)	Nature Works, U.S. Hycail, Netherlands Mitsui Chemicals, Japan Toyota, Japan Mitsubishi Chemicals, Japan	Nature Work Hycail HM; HycailL M Laceam U'z GSPla
	Poly (butylene succinate)	Showa High Polymer, Japan	Bionolla
Biosynthetic polymers	Polyhydroxy alkenoate	Biomer, Germany Telles, USA Mitsubishi Gas, Japan PHB Industrial S/A, Brazil Metabolix, U.S.	Biomer Mirel™ Biogreenm Biocyclem Biopolm
Modified natural polymer	Starch polymers	Novamont, Italy Rodenburg, Netherlands BIOP, Germany	Solanylm BIOparm Cornpol
	Cellulose derivatives	Japan Corn Starch, Japan Daicel Chemical Industries Japan	Cellgreen

Table 2: Commercially important biobased and biodegradable polymers for bulk applications and some of their sources [71]

Polylactic Acid (PLA)

Among the many different plastic composites investigated to date, PLA and polyhydroxy alkanoates (PHAs) have been the two most studied. This is because both of these aliphatic polyesters have mechanical properties such as plastic materials such as polyethylene (PE), polypropylene (PP) and polystyrene (PS). In addition, both PLA and PHA can be produced with renewable resources such as starch and sugar. And both will deteriorate under different conditions, although the degradation of PLA hydrolytic requires the onset of very high temperatures, i.e., ca. 608C. Modification of their cellular characteristics such as molecular weight, monomer sequence distribution and crystallinity can regulate the degradation rate of PLA [71] and PHA [72]. The PLA and its copolymers have been used successfully in the natural use and manufacture of drugs in the form of decaying sutures and matrix for drug delivery systems, respectively, since the 1970s [73]. impact forces and PLA temperatures are not sufficient for most applications. Therefore, at present, a complex stereo PLA produced from L-lactide and D-lactide, with a high ca. 2308C, in-depth investigation. As a result, the PLA appears to be the most popular.

Polyhydroxy Alkenoate (PHA)

Polyhydroxy alkenoates are a class of natural perishable plastic made from various chemicals (example: Cuprividus and cator). Other types of PHAs include poly-3-hydroxybutyrate (PHB), polyhydroxy valerate (PHV) and polyhydroxy hexanoate (PHH). PHA biosynthesis is usually caused by damage to certain organisms (eg PHA granules are then obtained by breaking down micro-organ [74].

Starch Blends

Starch mixing with thermoplastic polymers produced by mixing starch with plasticizers. Because starch polymers alone are stable at room temperature, plasticizers were added to a process called starch gelatinization to increase its crystallization [75]. While all starch is separated by decomposition, not all plasticizers. Therefore, the biodegradability of the plasticizer determines the biodegradability of the starch mixture.

Conclusion

From all above approaches and remediation method it can be concluded that the need of plastic bioremediation should be a future research priority and also finding the better biodegradable alternatives. Public awareness campaigns should be done to avoid the use of plastics because not only to the soil and water, it also harms our health and animal's life too. Also, we must avoid use of plastic and polythene as much we can. The next major projects should include the development of more biodegradable alternatives. If we didn't stopped here, we may have to suffer more.

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